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THE SYSTEMS ANALYSIS APPROACH TO ENVIRONMENTAL AND NATURAL RESOURCES MANAGEMENT IN THE BALTIC REGION

26-29 September 1988

Gdańsk, POLAND

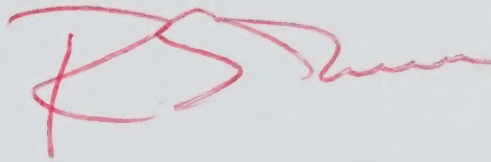
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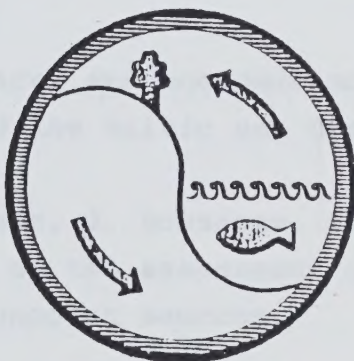
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UNIVERSITY OF COPENHAGEN

INSTITUT FOR ØKONOMISKE FAKULTET

THE SYSTEMS ANALYSIS APPROACH TO ENVIRONMENTAL AND NATURAL RESOURCES MANAGEMENT IN THE BALTIC REGION

by Dr. J. H. J. VAN DIJK

STUDY REPORT

NO. 10 IN THE SERIES OF STUDY REPORTS



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FOREWORD

INTERNATIONAL CONFERENCE ON THE SYSTEMS ANALYSIS APPROACH TO ENVIRONMENTAL AND NATURAL RESOURCES MANAGEMENT IN THE BALTIC REGION, 26–29 SEPTEMBER 1988, GDANSK, POLAND.

This Conference was organized jointly by the Polish and the Danish Operational Research Societies. Other related Societies of the countries of the Region were co-sponsors, together with IIASA, International Institute for Applied System Analysis Laxenburg, Austria. This was the first time a conference with such a theme was convened in the Baltic Region.

Sixty-one researches covering both Natural and Systems Sciences met at the Conference and Training Center in Sobieszewo. There were participants from all the countries of the Baltic Region. Moreover, other countries (U.S.A., Italy and Canada) were also represented.

The chief aim of the Conference was to provide a forum for the presentation and discussion of recent advances in analysis and solving of environmental and natural resources management problems and solving of environmental and natural resources management problems in the Baltic Region. The systems-analysis approach and international cooperation are strongly emphasized as means which can make sustainable development of such basins possible. Many high-quality papers were presented within the following areas:

- systems analysis in natural resources management
- Baltic basin geology and chemistry
- regional management, forests and agriculture
- ecosystems and fishing activities
- regional development and environmental issues
- decision support systems for environmental planning
- decision support for water management.

The papers combined ecosystem modelling with the systems approach focusing on both management and decision-making problems.

It has been a very difficult task to select the papers for this Proceedings out of a total

of 33 papers. The criteria have been both the quality of the presentation and the relevance to the main theme of the Conference. Moreover, we aimed to have a Proceedings of no more than 250 pages. The result is the monograph you got in your hands containing 17 papers covering the main areas discussed at the Conference. My thanks to my co-editors, Straszak and Ravn, for a very efficient team-work while editing this Proceedings.

Many of the papers at the Conference pointed out the seriousness of the environmental problems in the Baltic Region and the need to improve the management of the natural resources of this region. This type of problems does not belong to a single country, they have no borders, and therefore the need is for international cooperation and action before it is too late.

After many discussions, and since the above-mentioned problems will continue in the future, it was agreed to take some actions:

- (1) There is a need to continue with similar conferences. The next is already planned for November 1989 in Leningrad, U.S.S.R., with Academician K.Y. Kondratiev as a chairman.
- (2) The Third Conference will be in a Scandinavian Country, probably Denmark.
- (3) An international network dealing with questions of analysis, monitoring, modeling and managerial solution for national and international problems should be established.
- (4) The participants of the Conference should in their country inform politicians, decision-makers, other researchers and the public about the above-mentioned actions.

The Conference was well-organized, and our Polish colleagues from the Systems Research Institute, Polish Academy of Sciences, have done very good both planning the Conference and solving all practical problems. The very good atmosphere in Sobieszewo provided an excellent basis for discussions and interchanges between different groups.

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THE ROLE OF SYSTEMS ANALYSIS
IN ENVIRONMENTAL AND
NATURAL RESOURCES MANAGEMENT

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Abstract

The purpose of this paper is two-fold:

- to make the systems analysis community aware of the importance of dealing with the management of the environment and the natural resources, and
- to inform the "environmentists" of the possibilities of applying systems analysis to cope with complex large scale problems.

Finally, the paper also suggests some projects emphasizing the practice of systems analysis with social responsibility.

Keywords: Systems Analysis, Environment, Natural Resources

1. Introduction

Everyday news both in newspapers and TV present us with an increasing number of serious pollution problems in the environment (air, water, earth) and serious spoilage of the natural resources (fish, forest, wildlife).

Natural scientists have been dealing with such problems specially measuring the quality of the environment and analyzing some simple relations between input and output of some processes relevant for the environment. Engineers have designed techniques and machines to clean the environment of undesirable elements. These activities, although necessary in the short term, are in no way sufficient in the long term as basis for a sound management of the environment and natural resources. Radical solutions are needed not merely based in a technical approach but to a high degree based in political and economical strategies. These require deep analysis because the many problems are rather complex, highly interrelated and of large scale.

Systems Analysis is a young discipline, born during the Second World War, dealing with complex and large scale decision problems. It is characterized by:

- a methodology based on the systems approach
- interdisciplinarity
- use of computer technology to handle both large amount of data and complex situations.

In sec. 2, the methodological aspects of systems analysis will be outlined, see further Miser and Quade [1]. Natural scientists and engineers have been using some elements of systems analysis as for instance mathematical modelling or optimization/simulation techniques, but as we will see later this is not sufficient to cope with environmental problems.

Sec 3. presents the so-called logistic system, that describes the different sources of environmental problems and their close relation to the production and consumption sector. Identification of global strategies for management of the environment and the natural resources is also the subject of this section.

Some projects of immediate actuality in many countries are shortly outlined in sec. 4. Finally, the last section presents some final remarks.

The main purpose of this paper is two-fold:

- to make the systems analysis community aware of the importance of dealing with the problems of how to manage the environment and the natural resources and
- to make the "environmentists" aware of the possibilities of applying systems analysis to cope with complexity and large scale problems.

2. The systems approach

The systems approach is usually applied to solve decision problems, that is, problems where we have to choose among several alternatives to achieve some given objectives. Fig. 1 shows that the systems approach is composed of five closely interrelated phases:

a) Problem formulation

In this phase the loosely defined problem of reality is transformed to a conceptual model. Here some of the following tasks have to be solved:

- identification of the problem (framework and subproblems)
- definition of the subproblems for further analysis

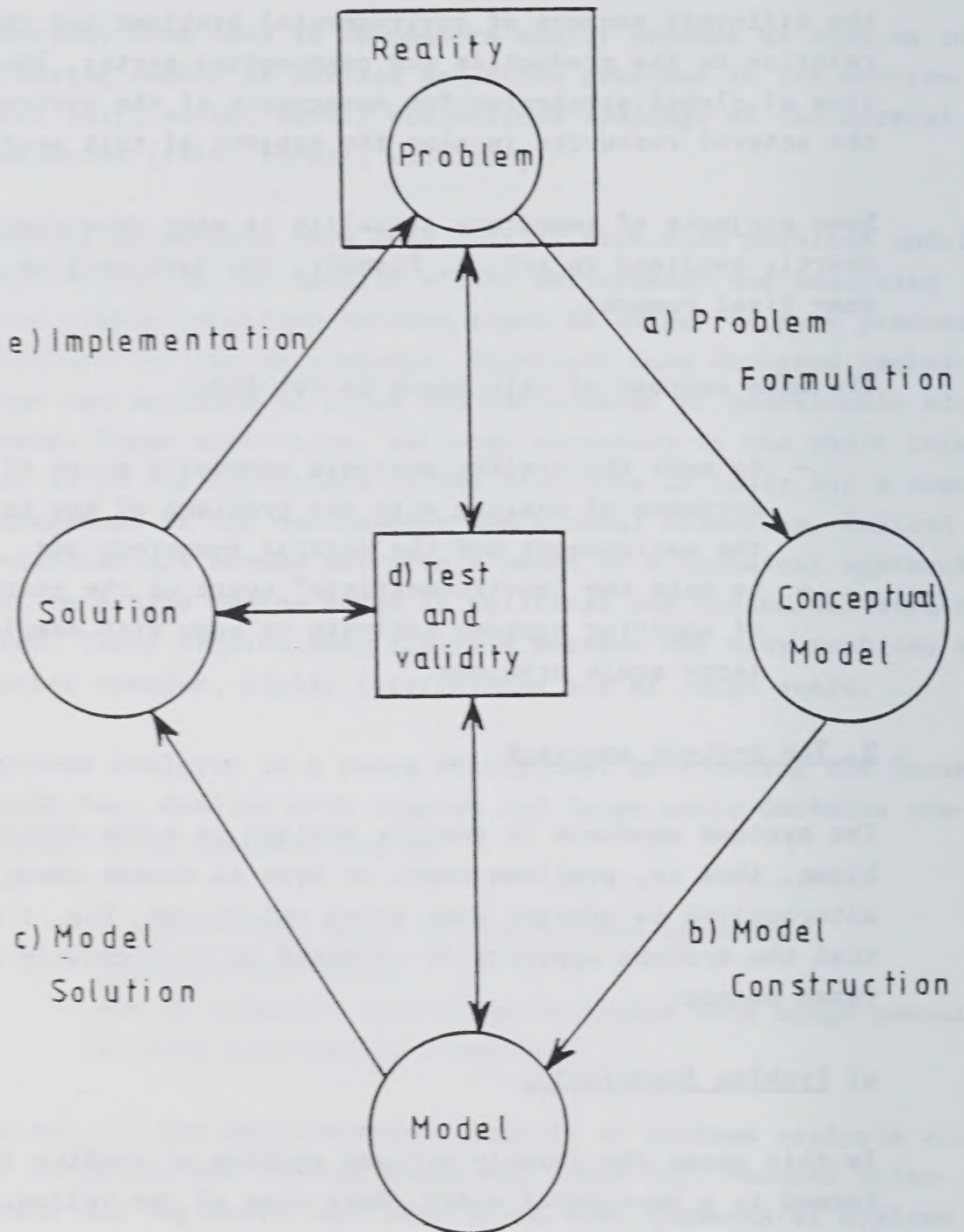


Fig. 1. The Systems Approach

- definition of goals and means
- specification of a practical strategy for a project

b) Model construction

In this process the conceptual model is transformed to a formalized model (a mathematical-, a logical-, or a computer-model).

Here some of the following tasks have to be solved:

- specification of the approach in what concerns the interplay between the decision-makers, the analysts, the model in construction and the actual system in study
- specification of the quantitative and qualitative aspects of the problem
- specification of the data structure and data-need
- specification of different routines and algorithms
- specification of computer hardware and software.

c) Model solution

In this phase different computer based procedures are selected and developed. These will be used to solve the model constructed. These procedures can be:

- classification system to reduce large quantity of data to usable information
- searching routines
- statistical methods
- optimization and simulation methods
- forecast methods
- cost-benefit analysis
- graphical and visual approaches

d) Test and validity

This is the phase where the obtained solution is tested in relation to reality, so that its properties are evaluated. Experimentation with the users of the developed approach is applied to evaluate both the solution obtained and the quality of the model.

e) Implementation

This is the last phase, where the model is used in real-life and where the model becomes a part of problem-solving and the day-to-day work in the organization in question. Here one has to be aware that implementation of models and computer technology in an organization is not only a technical/economical problem, but one has to take account of organizational, behavioural and social aspects. The implementation of "decision support systems" will usually cause changes in the structure of the organization, the contents of the work to be performed and of the working conditions. Here is needed a very strong interaction between the users and the analysts if suitable systems are to be implemented.

The process outlined in Fig. 1 is by no means a sequential process. Feedback (both forwards and backwards) and interactions between the different phases are usually applied.

We consider systems analysis as the practical use of the above mentioned approach to solve real-life decision problems. Systems Analysis is a broad denomination of a group of sister disciplines having in common the systems approach. Some of these are: Operation Research, Management Sciences, Decision Sciences, System Sciences, Cybernetics, Industrial Engineering, Artificial Intelligence and Expert Systems, etc. These disciplines usually differ in the kind of problems solved, or in the kind of models used. Some are considered as "hard" (mathematical) science while others are more oriented towards "soft" sciences. Usually, differences also arise depending on the role of the computer in the developed approach.

In this mess of disciplines we usually regard systems analysis as having a "tool-box" of models and solution procedures that can be used in connection with the systems approach. In practice, it is the actual problem to be solved that determines the

kind of tools to be used. We believe that future systems developed for problem solving will be "hybrid", that is, they will be a combination of different tools coming from the different disciplines and integrated by computer technology.

The big challenge to system analysis in the near future is to develop approaches to deal with complex problems in Society that have great impact both in the short and long term. One of this is the problem of Environmental and Natural Resources Management.

3. The Logistic System

Fig. 2 depicts what we usually denominate the logistic system, that is, the system that illustrates the flow of raw materials, goods, technologies, emissions and wastes, from the environment and back to the environment. During the last 20 years we have seen that in many countries this logistic system has become more complex and many problems have arisen with pollution and destruction of our natural resources.

It is the task of the State, both at national and local levels, to manage, that is, to control, regulate and legislate, the logistic system to reach some policies that will satisfy both consumers, producers and society as a whole. This is not an easy task neither in capitalistic nor in socialistic societies.

The management activities of the State up to now can be characterized as reactive, that is, wait for the problems to appear before doing something. Probably, some monitoring activities are done to register how bad the air, water, etc., are being polluted. If a problem has achieved a level where a solution is needed then usually the approach adopted is technical oriented, for instance if the level of emissions of a plant is too high then an upper bound will be fixed and the plant has to use filters. The results of such an approach is that restrictive legi

slation is developed increasing the control function of the State and more technology is developed and used to repair for the damages of the technological development. The continuous increase of environmental problems in the last 10 years has shown that this management strategy is not sufficient to save the environment and the natural resources.

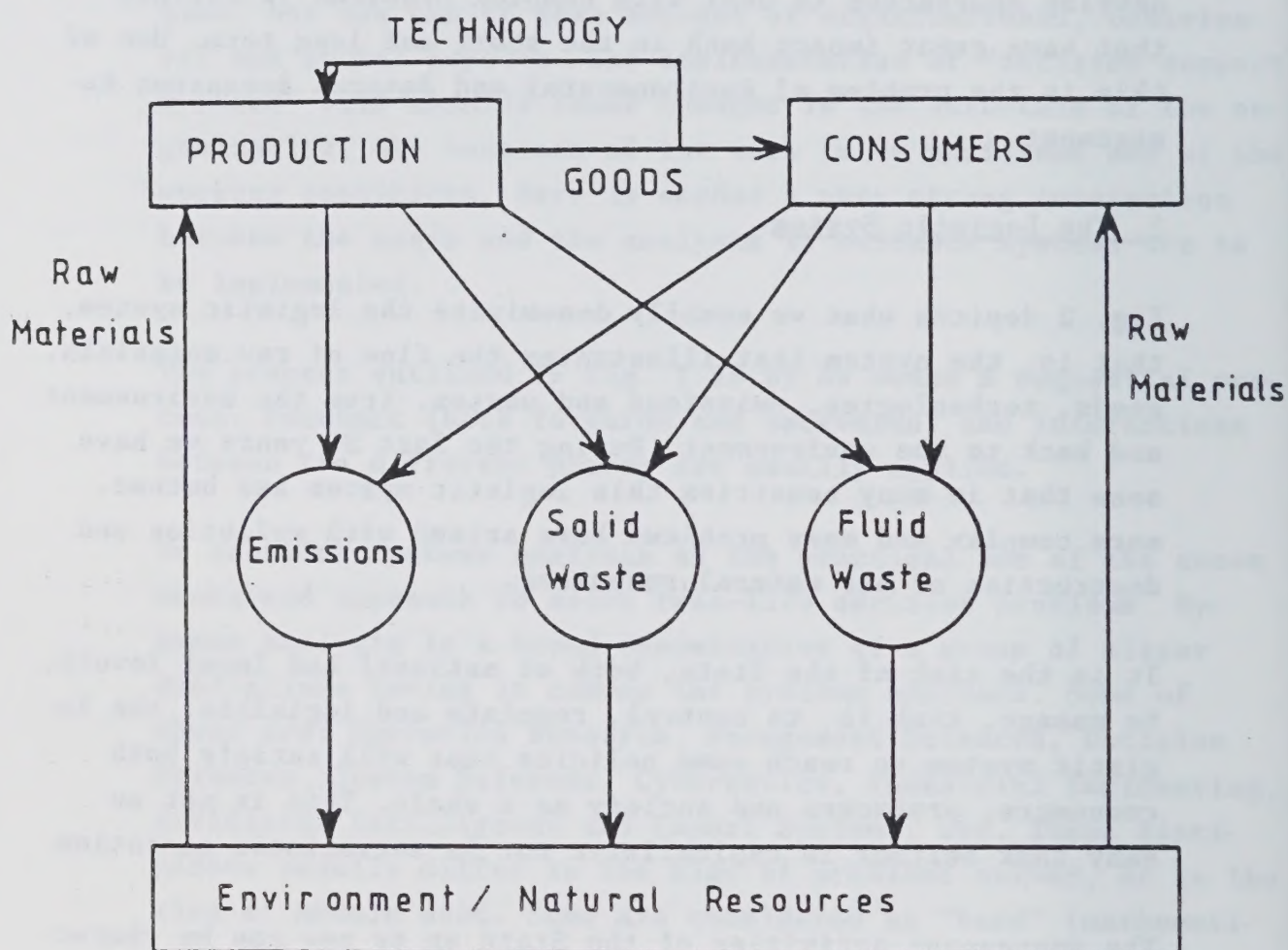


Fig. 2. The Logistic System

Therefore, the above described reactive management strategy has to be complemented with a proactive management strategy, that is the use of planning activities to forecast and avoid environmental problems and a better planning of our natural resources. This management strategy is a global approach that

will be the framework for partial problem solving (the technical oriented approach).

This management strategy is "socioeconomic" oriented using political, economical and social means to achieve the goals. Some examples are: regulations (usually economic) so that industry will use cleaner technologies and more appropriate goods and technologies; to inform and motivate producers and consumers to be more responsible about the environment and the natural resources; to support actively research and development in more appropriate types of technologies; to participate actively and constructively in international cooperation projects; etc.

The development of sound proactive management strategies demands an interdisciplinary approach, the problems are too serious to be left alone to natural scientists and engineers. Economists, sociologists and systems analysts should become more active in the above mentioned field to practice their disciplines with social responsibility. In this context the systems approach is a valuable methodology both at the global level to develop strategies and the more specific level for concrete problem-solving.

More specifically, in what concerns Denmark, it is within the field of waste management that we can register an increasing interest in proactive strategies and a common understanding that it is the only way to cope with environmental problems.

4. Some projects

In this section we want to outline some projects of immediate importance for the environment and the situation of our natural resources.

- a more systematic use of technology assessment (a systems analysis oriented discipline) within the State to support the development of "cleaner" technologies,

- to develop integrated and coordinated information systems to support decision-making activities of authorities at both local, regional, national and international level,
- to develop environmental information systems for industry so that the internal and external environment become an integrated part of management together with economics, technology and manpower,
- to solve real-life problems using the systems approach to forecast and simulate the future development of a given area,
- community work to inform and motivate people to participate in problem-solving activities, for instance some activities in waste recycling demand active participation of the community.

More concrete projects that illustrate the above mentioned list is the Environment Program Research Plan of IIASA (International Institute of Applied Systems Analysis) [2].

5. Final remarks

There is a lot of work to be done by systems analysts within this new field that has important consequences for the future of our societies. To identify, to formulate, to solve and to avoid problems is a tremendous task for our discipline.

Many of the papers at the Conference pointed out the seriousness of the environmental problems in the Baltic Region and the need to improve the management of the natural resources of this region. Very few papers presented solutions to real-life problems. This is not an untypical situation if you give a glance to journals and the work of research institutions all over the world. If radical solutions to so many serious problems have to be developed, then this situation has to change. We believe that system analysis has a rather central role to play.

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TOWARDS SUSTAINABLE DEVELOPMENT OF THE BALTIC REGION: AN ENVIRONMENTAL PERSPECTIVE

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1. Introduction

The Brundtland Commission has defined *sustainable development* as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED, 1987). In this paper, the idea of sustainable development is elaborated in the context of environmental management of the Baltic region.

2. Some General Thoughts on Sustainable Development

If *development* means *growth*, then development cannot be sustained. However, development also means *evolution*, usually implying that the system being considered is becoming "better" in some sense. (A value judgement is therefore involved.) When that interpretation is used, it is not difficult to imagine development that is sustainable through structural changes, technological break-throughs or continuous renewal (as in a forest where old trees die, to be replaced by young seedlings).

The sustainability of a natural ecosystem is rather easy to imagine. However, when contemplating sustainability of a managed ecosystem or indeed of a social system, three questions need to be posed:

1. Under what conditions is the ecosystem sustainable? Many managed systems are kept at a steady state through inputs of energy and economic subsidies. In the case of an agricultural system, for example, withdrawal of the energy required to run farm implements and to manufacture fertilizers, pesticides and herbicides would place severe stresses on the system.

2. For what purpose is the system to be used? If a sustainable forest is cut down, for example, the land may not continue to be sustainable (soil erosion could occur, or the water table could rise, creating a swamp).
3. In the case of human populations, at what standard of living is society to be sustained? Clearly many more people can be supported at the subsistence level than at the luxury level.

The conclusion to be reached is that *sustainable development* is a value-laden term, although this does not diminish its usefulness as an expression of the aspiration of society.

3. Some Ways that have been used to Ensure Sustainability of a System

Three approaches that have been used to ensure sustainability can be described in terms of the following phrases:

Maximum sustainable yield of a natural resource: A fishery or forest is often managed by assigning quotas, which in total do not exceed natural replacement rates. This is the basis for fishery agreements, for example.

Carrying capacity of a region: There is an upper limit to the number of people, animals or fish that a region or body of water can sustain. By establishing this carrying capacity, one could set limits on the number of people, animals or fish that could be supported. (This is another value-laden phrase.)

Assimilative capacity of a region: By determining the self-purification rate of a medium or region, one could estimate maximum acceptable emission rates into the system.

These are all reasonable approaches to apply under steady-state conditions. But the environment shows great variability as well as long-term change. As an example of the former, the number of fish that can be sustained in the Baltic varies from year to year, due to changes in the inflow of oxygen-rich water through the straits between Sweden and Denmark: this opens the possibility that if fixed values of *maximum sustainable yield* are used as a management tool, the Baltic fisheries will collapse from time to time.

With respect to long-term changes, there is mounting evidence that environmental changes in the next 100 years will be unprecedented in the history of civilization. For example, the climate in the Baltic region is likely to warm considerably, particularly in the winter half of the year. Present environmental policies generally are designed to keep managed ecosystems in a steady state, which is rather like swimming against the tide. Resilience (the ability to absorb shocks) is reduced by such a policy and systems become more and more stressed, waiting for a triggering event, be it a forest fire, a climate anomaly or an oil spill, to cause environmental havoc. These ideas have been elaborated by Holling (1973) and in the books of Clark and Munn (1986) and Walters (1986).

4. The IIASA Study on Future Environments for Europe

Over the last several years, IIASA has carried out a study: *Future Environments for Europe: Some Implications of Alternative Development Paths* (Stigliani et al., 1989). The ideas elaborated in that study are worth examining as a possible framework for long-term environmental management of the Baltic region.

The IIASA investigation is continental in scale, with a time horizon up to the year 2030. However, it should be emphasized that the objective is not to predict the future but to manage the present. Four socioeconomic development pathways have been selected for study:

- Present trends continuing
- High growth economy
- Environmentally-friendly economy in Europe: present trends continuing elsewhere
- Environmentally-friendly economy in Europe; high economic growth in many of the developing countries (e.g., China and Nigeria).

For each of these pathways, a set of plausible environmental scenarios has been developed, as well as a few so-called not-impossible ones. These scenarios are consistent with the development pathways selected. A high-growth economy implies, for example, a marked warming of the European climate by the year 2030, an average global rise of 1m in sea level (local changes need to be evaluated individually) and a serious decline in the boreal forest due to acidic deposition, oxidant episodes and mild winters.

Through the mechanism of *policy exercises* (Brewer, 1986), very senior policy people and scientists have met at IIASA and elsewhere for a couple of days at a time to discuss the implications of these development pathways and associated environmental "futures". Wherever possible, the policy exercises are supported by simulation models. The outcome has been:

1. a better understanding of policy constraints and scientific uncertainties in the process of formulating strategies;
2. a realization that the option "do nothing" is not to be recommended; instead, one should think long-term but act now!
3. an elaboration of eleven large-scale environmental dilemmas that face European policy-makers. Those of particular importance to the Baltic region are discussed below.

5. Some Particular Environmental Dilemmas in the Baltic Region

Reflecting on the long-term future for the Baltic region, we can hypothesize a number of not-impossible environmental changes by the middle of the 21st century:

1. A rise in sea level of up to 1 m.
2. Climate warming of perhaps 5° C, particularly in the winter half of the year.
3. Decline or possible death of the boreal forest, largely due to warmer winters but also as a result of continuing soil acidification.
4. Increased year-to-year variability in the hydrologic cycle.
5. Chemical time bombs due to the mobilization of toxic materials from soils and sediments partly as a result of climate change and sea level rise (Stigliani, 1988).

The resulting dilemmas of particular significance for Baltic countries are:

1. Water-use conflicts during periods of drought, which may occur with increasing frequency. In a study of Gotland, Jansson (1988) has related gross regional product GRP to water availability, showing that economic development on that island is already very subject to water constraints.
2. Soil and lake acidification. Even with the proposed 30% reductions in sulphur emissions, it is not certain that all damaged ecosystems will recover.
3. Forest wood supply shortages. By the year 2030, wood supply from Baltic countries could fail to satisfy demand. The dilemma is whether to reduce European emissions of sulphur and nitrogen oxides more than currently proposed, to change forest management practices, or to develop substitutes for wood products.
4. Coastal issues, particularly sea level rise. If the world oceans rose on average by 1 m, what would be the rise in the Baltic, and should long-term management strategies seriously contemplate such a possibility?
5. Chemical time bombs, e.g., seepage from toxic waste dumps affected by sea level rise, and leeching of pesticides from farm land that is abandoned or planted with conifers.

5. Towards Sustainable Development of the Baltic Region

The environmental changes and resulting dilemmas mentioned above fall into 3 categories:

1. those caused by poor environmental management in the Baltic region itself;
2. those caused by poor environmental management in other parts of Europe;
3. those caused by a global failure to control the emission of greenhouse gases, resulting in climate warming and sea level rise.

Environmental policy makers in the Baltic region are therefore constrained in the effectiveness of the actions that they could take in moving towards sustainable development. This is part of many of the dilemmas mentioned in Section 4.

Another problem is the *overabundance* of studies, research reports and data banks relating to environmental conditions in the Baltic region. See for example, other papers in these Proceedings and in the special issue of *Ambio* (Vol. 17, No. 2).

1988) on ecosystem redevelopment. What is needed most at the present time is not further studies but a synthesis of current work. This should be undertaken within a common understanding by the Baltic countries of the nature of their large-scale long-term environmental problems. One way of achieving this understanding is through policy exercises, using the IIASA experience in this field.

As a supplementary benefit of policy exercises, the environmental processes of most regional concern can be identified, permitting work to proceed on appropriate simulation models and on the identification of a set of early warning indicators of environmental change.

6. Sustainable Development

As emphasized in the report of the Brundtland Commission (WCED, 1987), sustainable development involves the global community of nations. However, one must start locally, and the experience gained in the Baltic region may not only slow down or reverse some of the environmental trends but may also set a good example for other regions to follow.

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The Coastal Seas Governance Project - an international comparative analysis of stressed coastal systems

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Abstract The coastal seas of the ocean constitute "the life support system" of the marine resources, and the economic and social activities of more than half of the world's population. They are the first areas of the sea to receive the waste products of man's exploitations of the natural resources. Areas in different political and geographical climates show similar symptoms of stress. The aim of the present study is to clarify how policy and management decisions are made in order to find mechanisms whereby scientists, managers and politicians can work together to attain long-term solutions of environmental problems. The project team incorporating scientists, lawyers, land-use planners, environmental economists and journalists selected four major, coastal areas for data collection and site visits: the Chesapeake Bay, the Baltic Sea, the North Sea and the Setonai-kai (The Inland Sea of Japan). Three additional systems: The Straits of Malacca, the South China Sea and the estuary-lagoon complex outside Sao Paulo, Brazil were also considered using written information. About 125 people were interviewed, comprising scientists, managers-administrators, politicians-political analysts, citizen groups and lawyers. Ca 260 written submissions were provided to the site visits teams and opened for creative analyses through frank and lively discussions. Our preliminary results are summarized in 10 findings and recommendations which reflect: 1. The need for an event for arising environmental issues. 2. The necessity of considering the total system through trans-disciplinary analyses. 3. The different power situation of the scientific community in the various areas. 4. The different degree of public participation and pressure. 5. The different effects of laws versus social contracts in improving environmental decisionmaking.

1. INTRODUCTION

The aim of this paper is to advocate that systems analysis of environmental and natural resources management in the end has to have a transdisciplinary character. We distinguish transdisciplinary from multidisciplinary through the involvement of several sciences in the former such as natural, economic, social and political sciences. Usually

research projects are restricted to one of those sciences and usually they are focused on one geographical region only. Inspired by the intensive activities in cleaning up the Chesapeake Bay, the largest estuary of the United States, situated on the east coast, the late Professor Ian Morris, University of Maryland, initiated an international project with the aim of comparing several coastal areas of the ocean degraded by man's exploitation of the natural resources. A presentation of the project including some preliminary results has already been published by Dr. Morris and our secretary Dr. Wayne Bell (1). Unfortunately Dr. Morris died just when he was preparing to start the final synthesis leaving his collaborators with a deep sense of loss and the impossible task of replacing his intuition, skill and enthusiasm. This paper is dedicated to his memory.

2. AIM OF PROJECT

The intention was not to focus on a comparison of the environmental conditions of the separate areas or of their different states of health. The aim was to find new and better ways of managing seas based on a knowledge-based cooperation between laymen and experts. Looking at the same basic problem in a different environment might make the key issues more easily recognizable.

3. IMPLEMENTATION OF THE PROJECT

3.1. Significance of coastal seas

The area between land and the offshore zone, affected by land processes through estuarine outputs and diffuse land runoff, by the ocean through upwelling/downwelling water transports and erosion, represents in many ways a special regime rich in diversity of both processes and organism species (cf 2, 3, 4). Rich access to nutrients both from land and from the shallow bottoms supports a high biological primary productivity and the coastal seas represent the life support system of economically important species of plants and animals. Many fish, crab and shrimp species spawn here and spend their early life in the coastal zone. The coastal systems act as a protection against the ocean's eroding agencies with significant examples like coral reefs and mangroves. The mineral resources of this area are fairly easy to exploit due to the shallow depths and closeness to land transportation systems. This borderland between land and sea has a special attraction for humans and tourism is worldwide an increasing industry. Between 55 and 70 percent of the world's population is supported by the coastal regions. The coastal seas thus represent a high esthetic and economic value and constitute an integral part of the land-ocean system which has to be exploited with caution.

3.2. Long-term management (governance) of coastal seas.

Well aware that the exploitation of the coastal resources and its consequences are widely discussed problems we spent an ample time trying to pinpoint the most pertinent questions to be answered for an

adequate background to the problem. A series of detailed questionnaires was at last abandoned for the following five, broad questions: 1. What information is essential? 2. What are the main components of the system? 3. Where are the greatest uncertainties and how to overcome them? 4. Where policies have proven successful, what mechanisms were responsible? 5. Is there a willingness to switch from crisis-reaction mode to predictive-preventing mode?

3.3. Participants

An executive committee was formed of 14 people with long experience of environmental problems within their respective fields: marine scientists, systems ecologists, environmental economists and lawyers, resource planners and managers, and journalists representing countries such as Canada, France, Japan, United Kingdom, United States and Sweden. *

3.4. Funding

The entire project was financed by private money and the support from following organizations is gratefully acknowledged: W. Alton Jones Foundation and Chesapeake Publishing Cooperation (USA), and Marcus Wallenberg Foundation (Sweden).

3.5. The areas chosen

The basis for the evaluation of systems suitable for analysis within the framework of the project is summarized in Table 1. Five criteria were regarded as essential for the scope of the problem: 1. A well developed law system, 2. a fair amount of data on the various aspects of the problem, 3. a significant level of disturbance of the system, 4. present work on a policy for the crisis, and 5. good access to information of the area. In order to classify the respective states of the different properties an arbitrary scale of 1 (low) to 5 (high) was adopted.

After much consideration four systems were selected for closer studies including site visits: the Chesapeake Bay, The North Sea, The Baltic Sea and the Setonai-kai (The Inland Sea of Japan). Soon the need for at least some comparison with the conditions in the developing countries became apparent and three areas familiar to one of the participants were picked out: the Straites of Malacca, the South China Sea, and the estuary-lagoon complex off Sao Paolo, Brazil.

* The Organzing Committee consisted of: D.Cater, C.Curtis, C.Lyons, I.Morris and C.Roosevelt. Additional members of the Executive Committee of the project were: B.Bayne, W. Bell, M.Bewers, P.Burbridge, R.Chesselet, J.Clark, R.Costanza, W.Eichbaum, B.-O. Jansson and N.Kumomoto. Active participants in the various site visits were: W.Bell, P.Burbridge, R.Costanza, C.Curtis, W.Eichbaum, E.Fraites, J.Gartland, M.Goad, H.Hughes, B.-O.Jansson, N.Kumomoto, C.Leider, and C.Lyons.

3.6. The site visits

Each of the four main areas were visited by a transdisciplinary team who had prepared themselves by studying basic literature on the area. The program of each visit had been arranged by the responsible committee member and the local people. Excursions were mixed with discussions and reading of the numerous documents and scientific papers which were distributed. Ca 200 written submissions were received from the four visits altogether and the extensive discussions involved some 125 people. The talks starting with short presentations by the local representatives and planned questions by the project participants usually soon turned into very open and frank discussions. The project has collected a vast amount of material and impressions which are now being synthesized and will successively appear in print.

4. RESULTS OF THE SITE VISITS

The extensive material of the site visits and generated issues are still in the state of processing and the final synthesis will be published elsewhere later this year. The description below is therefore concentrated to some of the main characteristics and a short historical background of the respective environmental problems to give some concrete background to the findings and recommendations summarized in section 5.

4.1. The Chesapeake Bay

This bay is the largest and most valuable estuary of the United States (5). Its main physical characteristics comprise:

Surface area: 6 500 km²
 Volume: 53 km³
 Mean depth: 8.4 m
 Residence time of water: 10 months
 Shoreline length: 13 000 km
 Drainage area: 165 000 km²
 Population of bay area: 9.5 million

The roots of the present crisis can be traced back to the beginning of the century when contamination of oysters through human wastes initiated the construction of the first US treatment plant. Rapidly growing population ran ahead of the treatment activities, however, and from the 1950's anoxia and fish kills were common phenomena. A new threat to the Bay was introduced through the power plants and thermal pollution became the area of concern of many scientists. Successively declining oyster and fish catches (Fig.1) started to arise the awareness of the public and the National Science Foundation stimulated large-scale interdisciplinary research on shoreline activity, nutrients and waste water treatment. This was followed by an Environmental Protection Agency (EPA) five-year-study of the Bay in

the middle 70's. The project was extended, however, mainly due to further increase in fish stocks, active public concern (Citizen's Program, Public Action Group) and strong and dedicated politicians. In 1983 a Chesapeake Bay Agreement was signed by the surrounding states and the EPA. Monitoring, research and planning programs started with the evaluation and renewal set to 1988.

Our site visit was carried out June 27 - July 5, 1986. From the numerous, lengthy discussions and extensive written documentation following points stand out as significant:

- * A strong public momentum. Especially from the beginning of the 80's "the heavy citizen involvement was the glue that holds all governance agreements together."
- * Absence of a long-term data base. The Chesapeake Bay Program now contains an extensive monitoring program for water quality
- * Lack of a conceptual model of the Bay
- * Recognition of the impact of agricultural management practises.
- * Law enforcement of established water quality standards as the main administrative way of executing necessary measures.

4.2. The Baltic Sea

This semi-enclosed sea is the largest brackish-water body in the world and probably the best investigated marine area in that size class (11). It is boarded by seven countries (Fig.2), receiving wastes from a large part of Europe through rivers and atmospheric fallout. A physical description stresses the shallow, stratified and stagnant character:

Surface area: 372 000 km²

Volume: 21 000 km³

Mean depth: 60 m

Primary halocline at 60 m depth as boundary between saline bottom water from The North Sea and surface water diluted by rivers

Residence time of water: 25 years

Shoreline length: 9000 km

Drainage area: 1 721 000 km²

Population of drainage area: 91 million

The deeper concern for the state of the Baltic Sea started during the late 60's when the interpretation of the long-term hydrographical measurements by the Fishery Board of Sweden revealed long periods of

anoxic conditions in the bottom water starting in 1952 (12). The scientists were the first to discuss proper large scale investigations but soon both The Swedish Environmental Protection Board and The Swedish Natural Science Research Council funded research on the changing conditions of the Baltic Sea. The anoxic periods have increased in frequency and the offshore levels of phosphorus and nitrogen have increased eight- resp. fourfold since the start of the century (Fig.2), mostly due to land runoff and atmospheric fallout. Alarming concentrations of mercury, DDT and PCB measured during the 1960's caused a high activity on all organizational levels from the scientists and the public to the politicians. This led to a successive banning of those substances in the Baltic countries. The mercury levels decreased rapidly, the DDT's and PCB's more slowly partly due to inefficient banning. The seal populations, especially the harbour seals, are now close to extinction, probably due to the PCB's.

The environmental problems led to the foundation of the Helsinki Commission in 1974 whose Convention was ratified by all seven states six years later with the establishment of a permanent Secretary. The Commission makes recommendations on regulation of pollution discharges but only for the international waters. Two informal scientific organisations, established in the 1960's, promote scientific work and standardize methods - The Committee of Baltic Oceanographers (CBO) and The Baltic Marine Biologists (BMB).

The Baltic site visit took place October 23 - November 1, 1986 when Sweden, Finland and Poland were visited. The open and friendly discussions revealed a different attitude to some of the problems. The Polish scientists blamed pollution for the condition and availability of fish, the Finnish fishery biologists also pointed out the decline of several species populations while the Swedish governmental experts stressed the increase of total catches of herring and cod. In the extensive reports of the discussions and in the written material following points are significant:

- * Environment is since long an important issue in Scandinavia
- * The environmental policies in Sweden and Finland strongly reflect the impact of the scientists, and the scientific organizations (CBO,BMB) are closely communicating with The Helsinki Commission
- * There is little control of agricultural runoff
- * The presence of a long monitoring program (since 1900) have been of great importance
- * Total ecosystem models have been frequently used

4.3. The North Sea

The North Sea is a fairly closed and shallow basin (Fig.3):

Surface area: 575 000 km²

Volume: 47 000 km³

Depth: 30-200 m

Total river discharge: 400 km³

Residence time: 11 months

Population of drainage area: sewage of some 31 million people enters the area

The water from the continental estuaries mainly flows eastwards along the eastern coasts. The river discharge from the east coast of the United Kingdom spreads through the central North Sea and leaves together with the continental flow the North Sea through the Skagerrak, flowing northwards along the Norwegian coast.

Many highly populated centers and large industries are since long established in the drainage area, utilizing the rich natural resources, including one of the World's most productive fisheries. Discharges from domestic and industrial activities, dredging, dumping and sediment transports from coastal activities like reclamation, drilling for oil and gas and a heavy shipping activity, all put a heavy stress on the North Sea system (14).

It is obscure what initiated the strong concern for the North Sea in most countries. Increasing frequency of toxic algal blooms, and mass invasion of jellyfish in the coastal areas indicated that the previous dynamics of the system was changing. Areas with anoxia due to increasing organic load and frequent fish kills occur especially in the German Bight and in Danish and Swedish coastal waters.

The present state of the North Sea is characterized by open waters with contents of critical substances slightly higher than those of the open ocean and highly stressed coastal areas. Here plant production has increased greatly, the oxygen levels are often critical, fish diseases are common, contents of heavy metals and hydrochlorinated carbons high in the sediments. The Wadden Seas and the German Bight are the most affected areas. The concentrations of most pollutants have not declined during the last five years.

The only coordinating body for the total North Sea is the Ministerial Conferences. The Oslo and Paris Conventions are only concerned with dumping resp. land-based pollution in the North Atlantic.

The site visit was carried out January 20-28, 1987 when the Netherlands and Great Britain was visited. The discussions with representatives of governmental agencies and science, with "free" scientists and environmental groups showed a principal different attitude to the North Sea problems. It was expressed by one participant as: "In the UK the burden is on the environment to prove it is being harmed. In Germany and the Netherlands, the burden is on Society to prove the environment is not being harmed".

The main issues, emerging from the site visit can be summarized as follows:

- A total systems approach has not been used
- There is little coordination of environmental data between the different countries
- A long-term monitoring record is missing
- There is a lack of trust and communication between scientists and managers
- There is no equivalent to the Helsinki Commission
- The public concern for the state of the North Sea is weak

4.4. The Setonai-kai

This semi-enclosed sea (Fig.4) was once made a natural reserve because of its beauty. Now it is a heavily stressed system (15). The main characteristics of Setonai-kai are:

Surface area: 22 000 km²
 Mean depth: 37 m
 River discharge: small
 Residence time of water: 15 months
 Total coastline: 6 000 km
 Drainage area: 47 000 km²
 Population of drainage area: 29 million

The immediate value of Setonai-kai to society is as a fish resource, the main catches being sardines, flatfish, and shrimp; as a receiver for wastes and as a recreation area. There is an increasing pressure from tourism on the already heavily utilized area.

The more serious environmental problems seem to have started in the 1970's during years of rapid economic growth. Heavily industrialized areas, the biggest being Kobe and Osaka (Fig.4) and intensive agriculture turned

Setonai-kai into an chemically stressed and eutrophic system and the public reacted. Frequent periods of anoxia occurred and there was a high frequency of toxic algal blooms - "red tides" (Fig.4). Fish kills were common and the fishermen became- and still are - a prominent pressure group. The Central Government reacted fast in spite of little scientific evidence. A special law was enacted in interim form (1973) which became final in 1978.

The main measures were focused on point-source control, for example decreasing the outflow of organic substances and phosphorus. The anoxia is now a minor problem. Also the original high number of oil spills has decreased but must still be regarded as too high. The main problem now is the red tides which have decreased (Fig.4) but still cause some ten fish kills a year. Of the present discharges one third comes from industry, one third from households and one third from agriculture and natural sources. Environmental standards have been formulated. There is an extensive monitoring program and a total pollutant load control where each factory has to measure and record the chemical oxygen demand in its effluent water. In 1980 the prefectural offices established guidelines for the reduction of phosphorus in the drainage area. They introduced "detergents without phosphate" on the market and appealed to the public to use it. Its use rose from 55 percent in 1980 to 94 percent in 1984. Following major statements emerge from the analyses of the Setonai-kai site visit:

- * A legal mechanism is missing in the conservation work. The officials "appeal" to the public instead.
- * The Environmental Agency is consulted in matters of exploitation but has no power of veto
- * When environmental standards are set they are generally followed
- * There are communication problems both vertically and horizontally in the prefectures
- * The scientists have no impact on the settings of environmental standards
- * The public concern for the environment is generally weak

4.5. The Third World

As the Executive Committee of the project as a whole paid no site visit to the developing countries we had to lean on the long experience of tropical systems of one of the members (P.Burbridge) and on written documentation.

The three areas considered: the Straits of Malacca, the South China Sea, and the coastal complex off Sao Paulo, Brazil all display a wide range of activities from agriculture, forestry and fisheries to tourism. The low standards of environmental assessment, planning and management is to great extent due to the inability to realize the strong interrelationship between the upland, coastal and marine ecosystems and to problems of inter-sectorial conflicts. This has led to an overexploitation of the natural resources, agricultural, urban and industrial pollution and a resulting reduction in the ability of the natural system to sustain development.

5. FINDINGS AND RECOMMENDATIONS

The project has collected a vast and diversified amount of data from personal impressions of sceneries and people to summarizing diagrams and statistical tables. It would take a lot of space and effort to give an adequate analysis and synthesis of this practical and theoretical effort in order to fully scrutinize explore the concept of governance. At this stage the Executive Committee has formulated a fair number of findings with attached recommendations of which I here excerpt ten which should be sufficient to transfer the essence of the project:

1. The central importance of coastal seas:

They constitute the life support system of 55-70 % of the world population. The conservation of their resource potential for social and economic development must be realized

Recommendation:

The principles of governance should be based on the fact that the terrestrial and marine environment form an integral part.

2. The need for transdisciplinary action:

There is a global failure to treat coastal systems as a whole. Natural, social and political sciences and cultural history has to be integrated. The lack of cooperation between resource economists and environmental scientists has hampered the development of a theoretical framework for the evaluation of coastal seas for regional development.

Recommendation:

- a. Immediate action including quantification of the long-term social/economic value of coastal seas
- b. New mechanisms of governance
- c. Broader definition of coastal seas and their drainage basins,

integrating bio-physical and socio-economic features

3. The importance of an informed public:

Education is the only permanent way to change public attitudes. Explaining the importance of sustainable development of earth's natural resources has been largely neglected.

Recommendation

Curricula for explaining the concept of sustainable development should be developed for educational institutions. Starting with the younger generation the message would successively reach the whole public.

4. The need for transdisciplinary research:

The discipline-oriented structure of the scientific community and the research foundations make it difficult to study the integrated large-scale systems of man and nature

Recommendation

Centers should be established for integrated studies of natural resources. Education programs for systems ecology and natural resource management should be initiated.

5. The need for an independent scientific community in the decision-making process.

Scientists hesitate to present general overviews and personal thoughts about coastal seas problems. Government decision-makers consult government scientists instead.

Recommendation:

Scientists should be encouraged to express publicly their opinion about human actions and coastal seas' conditions. Good communication between decision-makers and independent technical bodies should be established.

6. The use and abuse of models and modeling.

A wide range of models are currently in use in coastal seas, but they tend (like their creators) to be isolated from each other. Inability to recognize proper sources and sinks and to establish proper connections between relevant variables has often led to incorrect interpretation of environmental hazards

Recommendation:

The informed use of a complex, hierarchial, independent suite of models

is the most appropriate approach to the use of modeling of governance. The model building should be an integral, cooperative effort involving all the actors concerned.

7. The dynamic nature of coastal seas and their governance.

All aspects of coastal seas are constantly changing. Any attempt to understand needs for governance changes depends on good records showing long-term trends of environmental degradation. There are few examples of such records.

Recommendation:

A proper baseline monitoring program is necessary for assessing the health of coastal seas and their watersheds. The sampling program must be related to the time and space scale variations.

8. The need for conflict resolution.

The observed examples of governing of coastal seas range from passing increasing rigorous laws and using courts to resolve conflicts and punish the law-breakers to basing environmental protection actions on volunteer agreements that link mutual self-interest to economic arrangements.

Recommendation:

- a. Decision-makers should spend more time finding the common ground between different interest groups.
- b. Social contracts between industry, governments and citizens should complement legal approaches to the management of coastal seas.
- c. Management policy needs to encourage more volunteerism - non-legal, non-regulatory, and non-prescriptive - on the part of the public.

9. Science/Policy/Management communications.

Clear scientific information, effective communication, receptive and responsive politicians and committed government officials are all needed for a successful governance. Our field studies suggest that these factors almost never coexist.

Recommendation:

- a. Establish independent and relevant science panels to communicate with policy makers.
- b. Enhance the exchange of information between government and managers about what is relevant.
- c. Multiple pathways should exist for good (technical) information to get into government decisions.

10. Funds and uncertainties.

The inability of political decision-makers to deal with risks from chronic, low-level pollution makes it difficult to design management systems that are proactive rather than reactive.

Recommendations:

Attempts should be made to calculate the environmental costs of a worst-possible case scenario. Special trust funds should be set aside to secure financial resources to become available for taking actions against any future environmental damage and threats to human life or property.

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System	Multiple jurisdictions	Research base	"Stress" index	Level of policy activity	Access of information	Sum
North America:						
Chesapeake Bay	5	5	5	5	5	25
Great Lakes	4	4	5	5	5	23
Gulf of St. Lawrence	1	4	2	1	5	13
South America:						
Gulf of Guayaquil	1	1	5	5	3	15
Europe:						
Baltic Sea	5	5	5	5	5	25
North Sea	5	5	3	5	5	23
Adriatic Sea	4	3	3	4	4	18
Black Sea	4	2	5	2	1	14
Middle East:						
Arabian (Persian) Gulf	5	3	5	4	4	21
Far East:						
Inland Sea of Japan	1	3	5	4	4	17
Gulf of Thailand	2	1	4	4	4	15
Pearl River Estuary	1	2	4	5	3	15
Gulf of Papua	1	1	3	4	3	12
Bay of Bengal	1	2	3	2	3	11

Table 1. Stressed large-scale coastal systems and their main "governance characteristics". The ranking scale is arbitrary from 1 (low) to 5 (high). Adapted from (1).

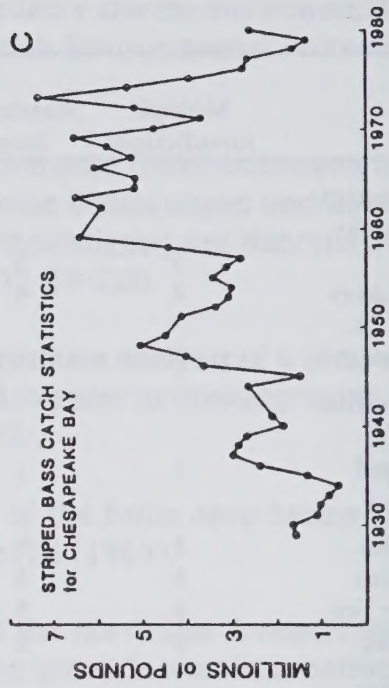
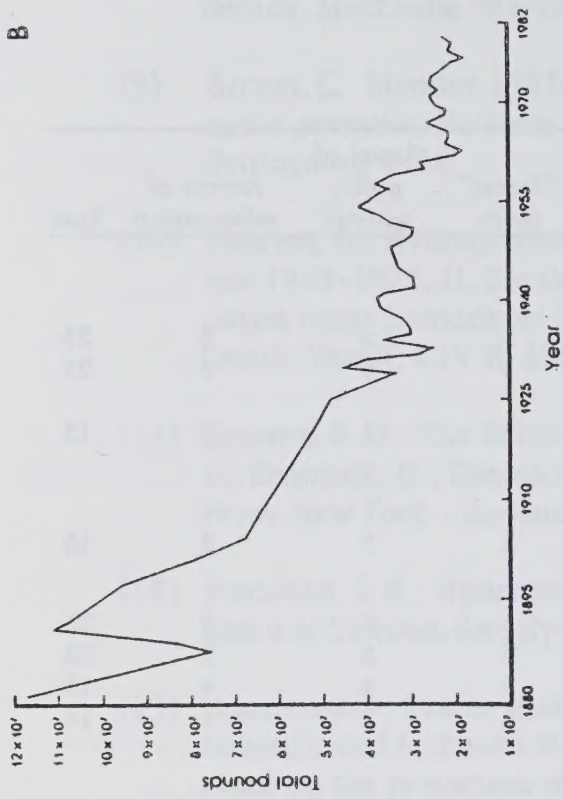
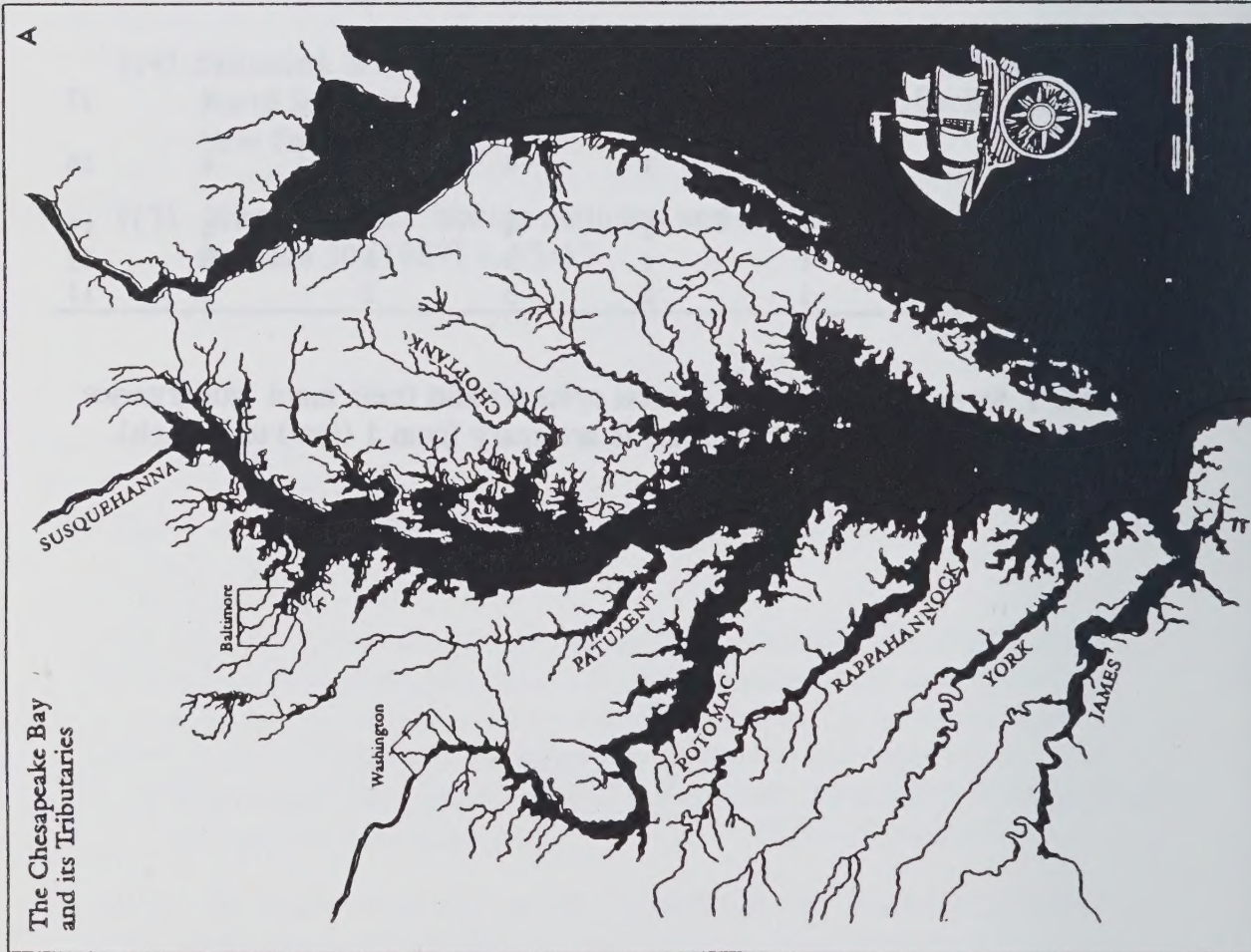


Fig. 1. The Chesapeake Bay estuary. A. Topographic map (6). B. Landings of chucked oysters 1880-1982 (7). C. Striped bass catch statistics 1929-1980 (7).

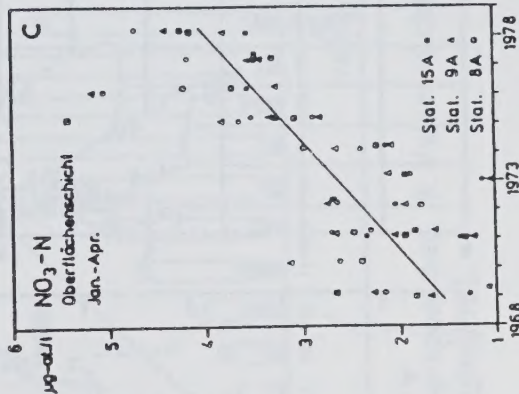
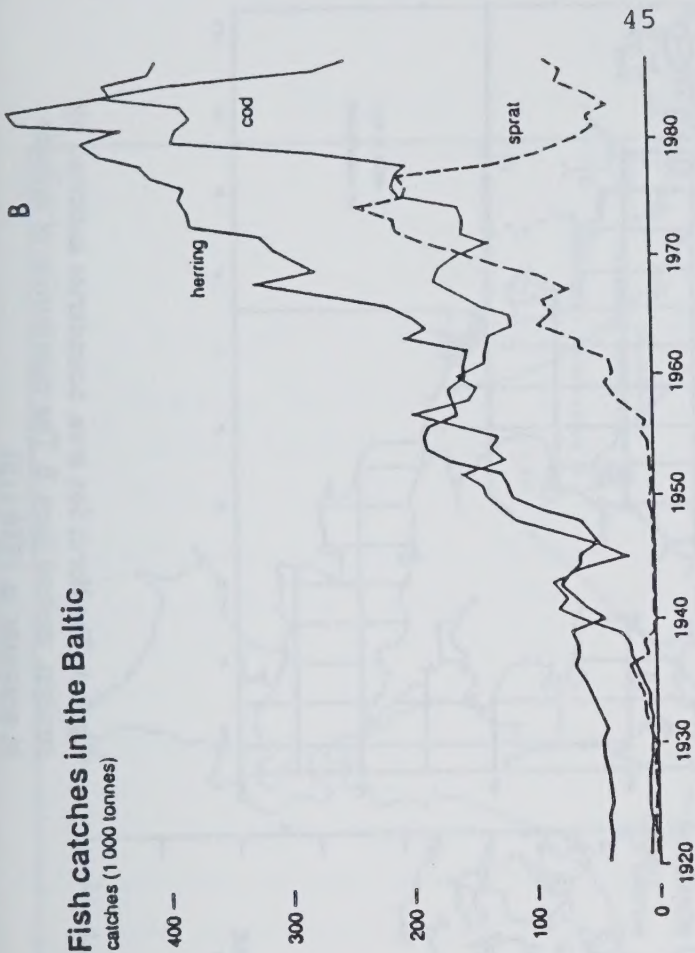
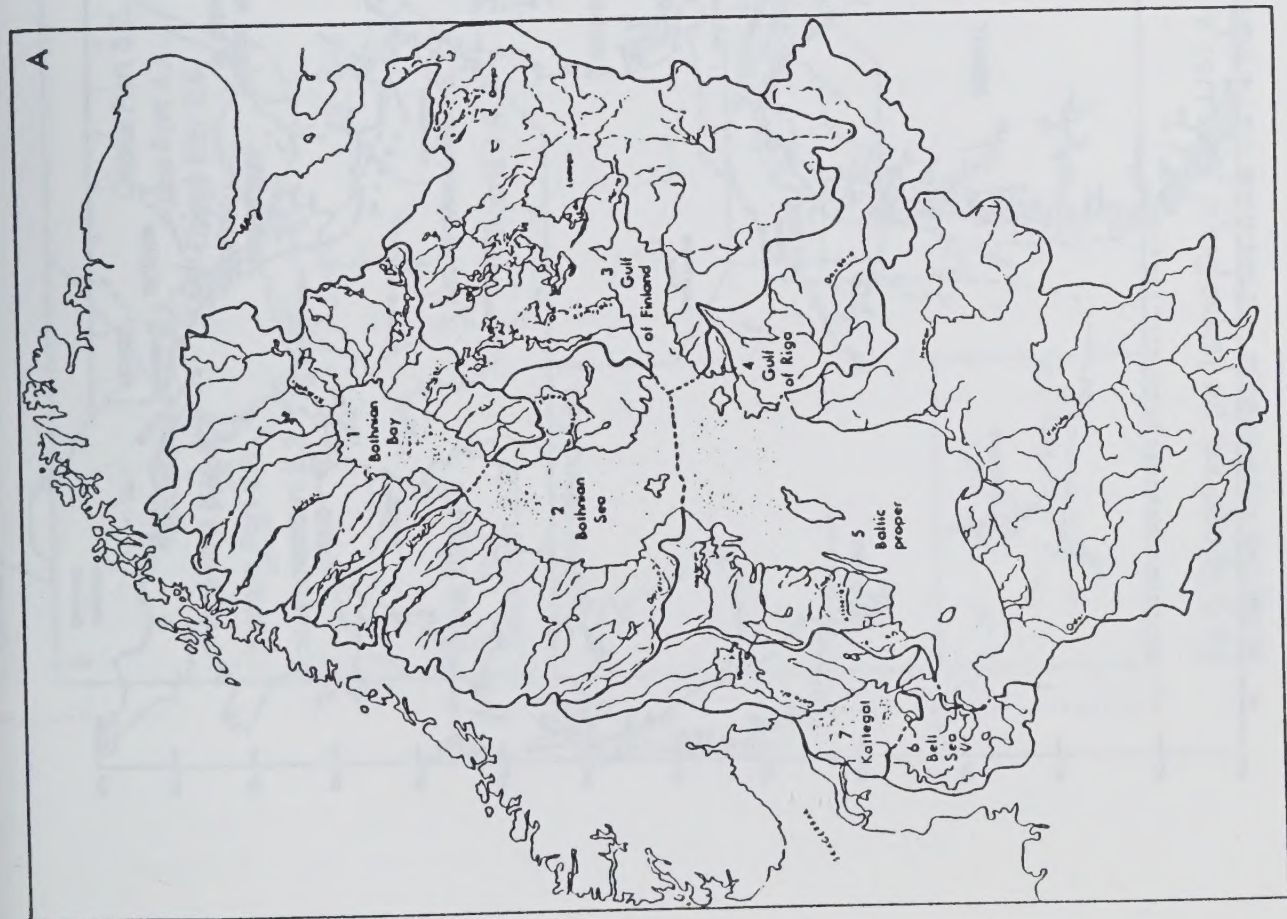


Fig.2. A. The Baltic and its drainage area (8). B. Total landings of herring, cod and sprat 1920-1985 (9), on data from The Fishery Board of Sweden and G. Otterlind. C. Concentration of nitrate in off-shore surface water of the central Baltic 1969-1978 (10).

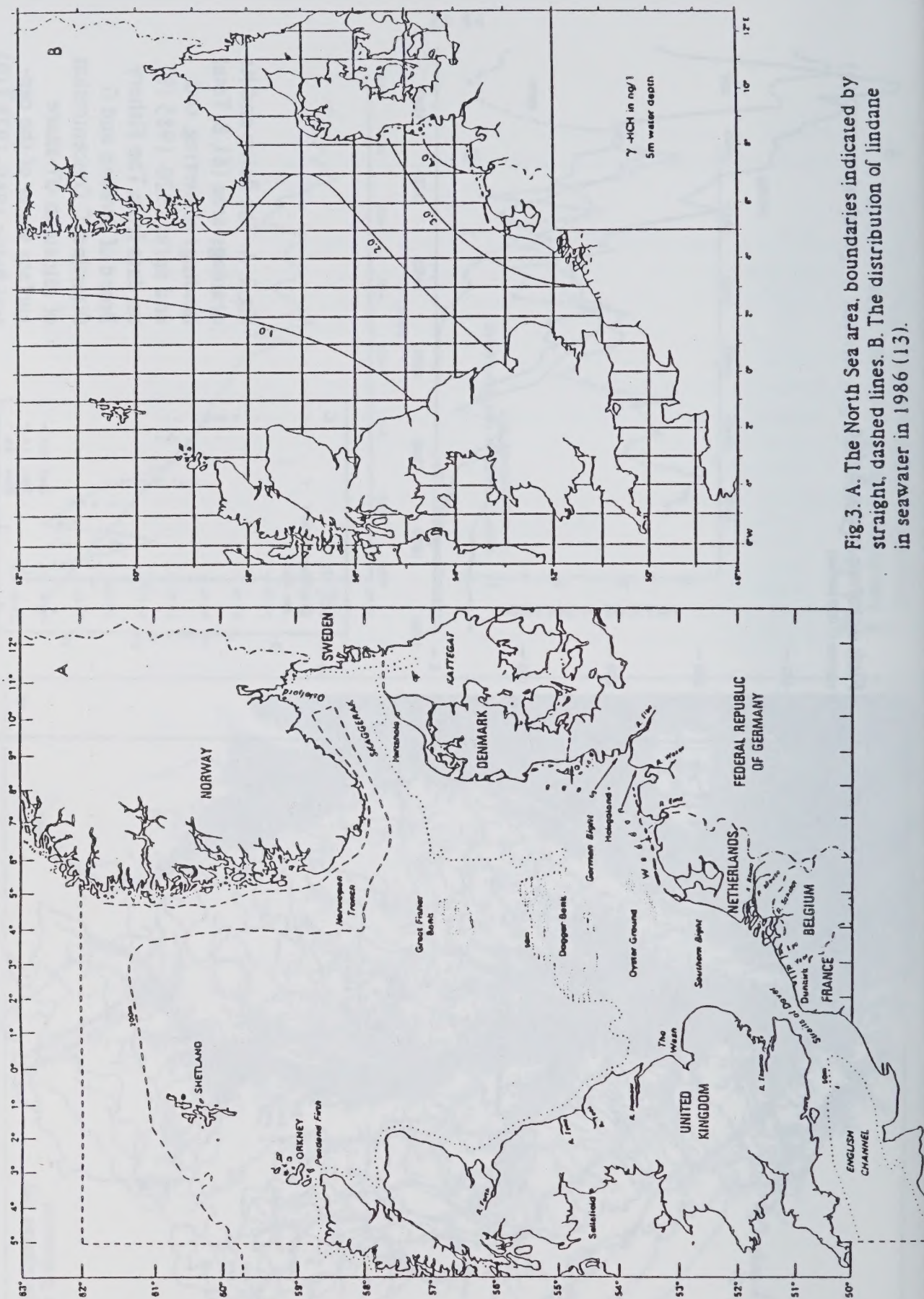


Fig.3. A. The North Sea area, boundaries indicated by straight, dashed lines. B. The distribution of lindane in seawater in 1986 (13).

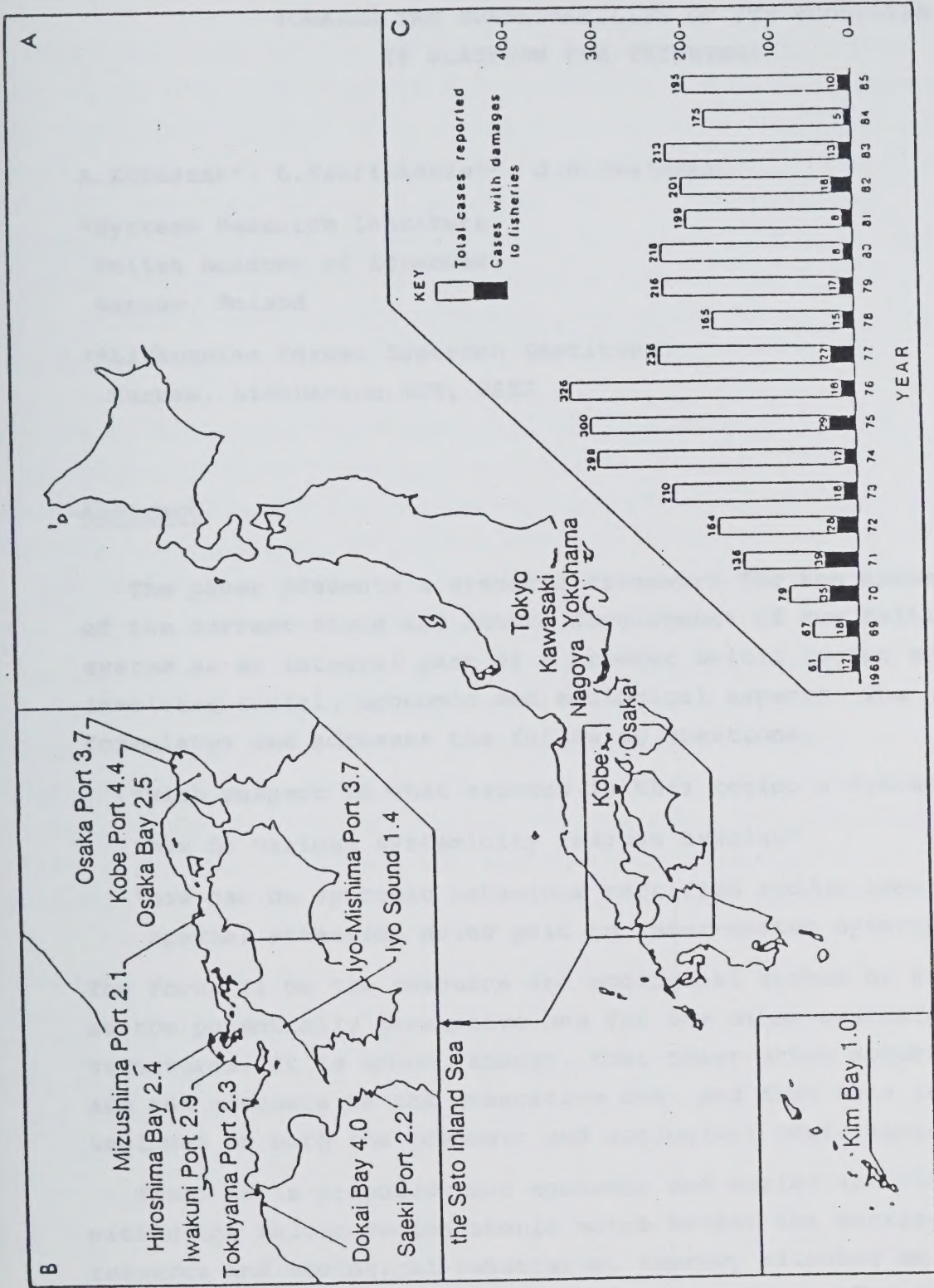


Fig. 4. Setonai-kai, the Inland Sea of Japan (16). A. Topographic map. B. Values of chemical oxygen demand (COD) in mg/l in various Bays. C. Frequency of red tides in 1968-1985.



INTEGRATED REGIONAL DEVELOPMENT OF THE BALTIC REGION
TOWARDS THE SUSTAINABILITY OF ITS ECOSYSTEM
(A PLATFORM FOR THINKING)

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Abstract

The paper presents a systemic framework for the assessment of the current state and future development of the Baltic ecosystem as an integral part of a broader Baltic region system involving social, economic and ecological aspects. The paper formulates and addresses the following questions:

*with respect to what aspects is this region a system?

*how do various systemicity reaches overlap?

*how can be systemic behaviour rectified and/or improved, special attention being paid to inter-system synergy?

The focus is on the resource and ecological system of Baltic, as the potentially generative one for the other systemic structures. It is shown, though, that these other structures are not adequate to the generative one, and that this inadequacy impinges on both the economic and ecological performance.

Thus, it is proposed that economic and social activities within the Baltic region should match better the variety of its resource and ecological substratum, thereby allowing smoother and more rapid development of the region and preservation of the sustainability of this development.

Examples range from economic cooperation and transport to tourism and recreation, and nature protection.

1. Introduction and problem outline

That Baltic and its closest surroundings should be treated as a "problem area" has been recognized some time ago by the corresponding scientific communities, by the public at large and by the political and administrative bodies of the Baltic-adjacent countries. Several particular questions arise, but obviously the leading codeword is "environment".

The present paper is meant to provide a few hints related to the scope and purpose of the Conference. Thus, it tries to create a somewhat different platform for thinking - and therefore also action - about the problems already mentioned. This platform is a broader one - in terms of geography, scientific disciplines involved and the manners in which the questions are approached.

1.1. A region and a system

In looking at the Baltic and its problems let us first ask a question concerning a broader area - that of the Baltic itself and the surrounding countries, provision eventually made for appropriate watersheds. Namely, does thus defined "region" make sense? and, if so, with regard to what aspects? Can this perspective help in solving or at least alleviating the problems mentioned? or perhaps other problems as well?

When referring to the notion of a "region" one may be placing himself on one of three levels of understanding of the term: First, is the common language, in which it seems obviously acceptable to speak of the "countries of the Baltic region", (meaning, roughly, the Scandinavian countries, the two German states, Poland and the Baltic republics and areas of the USSR), second - a simple criterion, like the one used in the expressions of the kind of Middle East or latin America. The third level, though, requires a more precise definition of what constitutes, and what not, a region. Such a definition involves usually a kind of a more consequent systemic criterion. That is why in discussing this item we shall refer to a minimum set of appropriate systemic requirements, encompassing both the natural endowment and the man-made structures.

1.2. Objectives, conflicts and knowledge

When defining a system one has to consider relations existing within the system or at its boundary, and/or objectives which give rise to or at least pertain to the system. For the case at hand it appears obvious that there are some unifying objectives coexisting with the conflict-generating ones. Not surprisingly, it is the conflicts arising therefrom that are one of the first signs of an objective systemicity. For a participant there are several ways of dealing with a conflict, depending upon his position and objectives. They may range from conflict avoidance through compromise-seeking or alliance-formation down to a hard no-deal stance. It may therefore be asked whether there is a way to improved cognition and conflict resolution in such a situation; the one that would enhance synergy within the system. (While it is obvious that certain potential synergy is inherent to a system, it must, for practical purposes, be put to work).

The present paper ventures an answer which consists in broadening the platform of knowledge and of technique. Namely, it is assumed that many of the problems encountered can be more easily solved when analysed through a broader spectrum of causes

and consequences, belonging usually to the domains of different scientific disciplines. Thus, it is proposed to create a model-based knowledge pool, encompassing not only particular domains in their regional geographic stretch, but also very tightly connecting the domains among themselves. Thereby potential synergy is importantly enhanced. Additionally, there arises the question of "common language", which does not pertain solely to conflict situations. Here, the paper tries to convey the conviction that application of the "knowledge engineering", "modelling" and "operations research" techniques may provide the bases for such a common language. Furthermore, whenever common language may lead to certain common grounds, to areas of cooperation, the techniques mentioned should truly help in determination of these common grounds. Eventually, even solutions to conflict situations or best alternatives in choice situations could be determined as well.

Note that certain positive experiences with that respect have been gathered in the course of activities conducted over almost ten years at IIASA in connection at the "integrated regional development" domain, see e.g. Sawaragi and Straszak (1982). These experiences involved international cooperation of scientists from countries with different socio-economic systems and from various backgrounds:

1.3. Time dimension, risks and opportunities

The question arises whether the time has already come for such a "systemic" - broad-minded, but also largely formalized approach. There may be the following doubts and obstacles:

- * forced early application of "knowledge engineering", "modelling", "conflict resolution" and related computerized techniques may turn out to have significantly worse cost-benefit relation than proceeding according to "business as usual", that is - waiting for the natural ripening of the particular questions and domains in terms of international and inter-domain overlapping, and the resulting language as well as knowledge improvements,

- * do these techniques really offer already much enough to justify appropriate investments and delays there, where responses to questions are needed immediately,
- * there is a risk related to additional cognitive capacities involved in conflict situations, namely, that these additional capacities might uncover as yet dormant conflicts or make the ones already active still more acute.

The authors of the present paper propose the following answers to these doubts and reservations:

- ** there are problems related to the development of the Baltic region which need imminent solutions and with regard to which, in view of their, significance, the risks mentioned not even may, but should be undertaken in order to secure adequate probability of solving these problems at all,
- ** it should be kept in mind that "crises are also opportunities" and in the case considered the opportunity would consist in eventual creation of the broader cooperation platform involving definition of
 - the hierarchy of objectives for the integrated development of the Baltic region,
 - the goals to be attained within this hierarchy,
 - the trajectories of attainment of these goals, stretching several decades into the future, since time constants of the ecological and resource processes are of that scale.
- ** in the domains and in situations where giving explicit answers to the latter problems may truly not be feasible yet, there should be an early recognition of the potential gains and losses from lack of adequate, critical mass of knowledge at the right time, so that a "grass roots movement" must be put to action leading to creation of a common understanding of problems, opportunities and threats: one may think of investments into knowledge, of the roles played by scientific communities, especially organized through

associations or other bodies and their contacts, as well as, more concretely, regional knowledge centers, oriented at enhancement of the systemic synergy; what would be important in this horizontal, as opposed to vertical, scientifically based "systemization", is information thruflow, so essential to this age, not only, and not so much in terms of quantity as in terms of quality and accessibility.

Thus, various responses to this challenge are possible, as driven by necessity and possibility. Let's hope that they will shape a promising perspective for the things to come, but let's also work for that purpose.

* * *

In subsequent chapters of the paper some of the points here raised shall be illustrated in more details and answers to some of the questions shall be ventured.

2. Regional systemicity and sustainability

It is systemic features pertaining to a geographic area that make a region out of this area. The system-wise decisive features may be of purely geographic, natural, environmental, economic or social nature. Of course, various features, or criteria, would define various regions - in geographical terms. On the other hand these features objectively are, or at least might be closely interrelated, so that ultimately a "multicriterial" definition of a region would turn out quite unambiguous. (It is true, though, that in practice the interfeature relations are usually assessed via simple correlations). The fact that essential features may be closely interrelated does significantly influence the choice of these features as well.

Thus, this section is devoted first to some thoughts on the nature and assessment of systemicity, and then to an illustration for the Baltic region.

2.1. Assessment of systemicity

A few quite superficial remarks shall be forwarded, related to practical assessment of systemicity.

Two notions are crucial with that respect: that of relation and of objective. It is almost obviously intuitively understood, that out of a set I of entities (a "universe") numbered i , $i = 1, \dots, \text{card } I$, a subset A_q may constitute a system, $A_q = i_1^q, \dots, i_p^q$, $p < \text{card } I$, if its internal relations are stronger than its relations with the rest of the universe. Thus, if, having for each pair of entities $(i, j) \in I \times I$ a number $s_{ij} > 0$ reflecting "connection", i.e. the strength of relation between i and j , one obtains:

$$S(A_q) > S(I - A_q, A_q) \quad (1)$$

where $S(\cdot)$ and $S(\cdot, \cdot)$ are aggregate "connection" functions, of, speaking roughly, positive and monotone nature, preferably normalized, then such an A_q is considered candidate for qualification as a system. For more precisely defined $S(\cdot)$ and $S(\cdot, \cdot)$ more adequate system definitions can be formulated. Suffice here to say, that among the various $A_q \subset I$ satisfying (1) there may exist their subsets $\{S_I^r\}$ such that $A_q \in S_I^r$ form separate hierarchies. In such a case from each hierarchy the maximum cardinality subset is picked, i.e.

$$\text{card } A^{r, \max} = \max_{A_q \in S_I^r} \text{card } A_q \quad (2)$$

In case of overlappings of $A^{r, \max}$ the differences

$$D_S(A^{r, \max}) = S(A^{r, \max}) - S(I - A^{r, \max}, A^{r, \max}) \quad (3)$$

are considered in addition to previous conditions.

Relations (1), (2) and (3) do refer to what can be called "connective systemicity", and having reasonable S , can be relatively easily assessed for not too numerous I . It can, however, be justly argued that ultimately, when defining a system one is referring, directly or not, to a certain "purpose" or "objective" with regard to which the system is formed. These purposes and objectives may be of external origin - which is often the case when a system is being shaped, designed etc., of internal origin, like in creation of alliances in game theory or in real-life conflicts and negotiations, and finally they may be of neutral origin: when, for instance, resource-and-ecological systems are being delineated according to their objective features. In accordance with this view relations used to assess connectivity among the entities ("elements") distinguished result from application of transformations reflecting given objectives.

Thus, if s_{ij} and S are defined via a certain transformation Q , reflecting pertaining objectives, one can use the procedure outlined before, including (1), (2) and (3). Still, it is usually much more practical to apply these transformations directly to $i \in I$ and $A_q \subset I$, so that candidates to systemicity are identified through:

$$\frac{1}{p} Q(A_q) \geq Q(i^q) \quad \text{for all } i^q \in A_q \quad (4)$$

$$\text{with } \frac{1}{p} Q(A_q) > Q(i^q) \quad \text{for at least one } i^q \in A_q$$

and, in an analogy to (2) and (3), whenever hierarchies S_I^r exist analogously to the previous ones, the most proper candidates are chosen with

$$\max_{A_q \in S_I^r} \{ D_Q(A_q) = Q(A_q) - \sum_{i^q \in A_q} Q(i^q) \} \quad (5)$$

corresponding, again, to $A^{r, \max}$, which cannot be confused with the one determined with (2) and (3), since either the first or the second one is referred to only, and even if foundations for both are present, they are aggregated.

"Objective systemicity" is computationally far less obvious than the "connective" one. Still, it is a far more powerful concept and is the only one to apply in case of designed, potential systems, as distinguished from the ones already existing.

One more comment: connective features and measures are the subject of cluster analysis and graph theory, while objective systemicity can be studied and assessed via game theory, mathematical programming, control theory etc.

2.2. Assessment of sustainability

Assume that a system has already been defined, composed of elements numbered i , as before, and characterized by feature values x_i , interrelated by the relation complex S , denoted altogether $A(I, X, S)$. With regard to thus defined systems the notion of stability has long been used. For our purposes it is more important to be able to define and assess "sustainability" meaning by it the capacity of the system, under a class of development trajectories externally defined, to maintain certain minimum levels of some definite features, crucial from the point of view of the overall system's characterization. Thus, sustainability, for a given system and the minimum characterization, determines, indirectly, the development trajectories. These trajectories result from certain rules of interrelations among elements i and their feature values x_i .

Hence, for the system $A(I, X, S)$, it can be said to be Sustainable with regard to $\{x_{ik}\}^*$, $i \in I$, $k \in K$ - the set of features, under the development rule R^* , where any $R \in E_R$ determines uniquely the trajectories of certain x_i , $ik \in I_R \times K_R$, $i^*k^* \in I^* \times K^*$, if for this R^* the values of $x_{i^*k^*}$ cannot be driven out of a prespecified set $E_{i^*k^*}^S$, related to $\{x_{i^*k^*}\}$, called sustainability domain. Analogously, one can define the class of sustainable development rules, $E_{i^*k^*}^R$, with regard to the same $\{x_{i^*k^*}\}$.

It is obvious that assessment of sustainability is far more intricate than the very definition of the system. It would namely involve, in practical cases, analyses referring to control theory or, more broadly speaking, to dynamical systems theory, with special emphasis on non-trivial systems of differential equations. Still, in the process of definition of a system a number of prerequisites for the assessment of sustainability can be formed, so that at least reasonable guesses can be made.

3. The Baltic Region Case

In accordance with previous considerations the sequence of proceeding, even if aiming at providing just a well-based illustration for our propositions, is to first define the set of elements $\{i, x_i\}$, $i \in I$, then, generally, interactions among these elements, and measures related to these interactions, i.e. ultimately s_{ij} , $S(\cdot)$, $S(\cdot, \cdot)$ and even $Q(\cdot)$. Finally, systemicity and its aspects could be assessed and hints as to sustainability formulated.

3.1. The potential systemic layout: elements and structures

In order to properly analyze the potential regional system, composed of previously mentioned countries as, roughly, elements, let us make the distinction into:

- * the underlying physical (natural) resource subsystem,
- * the socio-economic subsystem corresponding to the resource subsystem;
- * the institutional subsystem corresponding to the previous two

Note that for the object considered, the Baltic "region", as well as anyway, in general, these subsystems may contain segments which are "common" and which are "separate", though the distinction is for our pinposes secondary.

The subsystems distinguished can be perceived according to three reaches (see Fig.1):

- ** concerning directly the water body of the Baltic;
 - ** concerning the "tributary and peripheral" area of the Baltic;
 - ** concerning the indirectly influenced and influencing areas;
- where the notion of "area" is used in a broad meaning, encompassing also the socio-economic activity space.

It is within the thus outlined system structure that the components, listed in Table 1 can be, roughly, distinguished. As a comment suffice here to state that some of these components should obviously be further disaggregated in order to account for the underlying systemic organization (e.g. biota according to species, trophic levels and or feeding chains), and that this lower level systemicity is mainly seen through three kinds of dynamical processes:

- *** reproduction and feeding,
- *** (other) natural interactions (mechanical), and
- *** distribution, share and cooperation,

where mechanical interactions concern the abiotic natural processes, while cooperation may encompass also conflict situations.

Table 2 presents an overview of the inter-component dependencies, giving, possibly, rise to systemic behaviour. Cases marked with an asterisk present dependencies of essentially cross-boundary nature. Another representation of subsystems and their components is provided, after Kajriukštis and Espejo (1986) in the diagram of Fig.2, which tries also to provide an idea of possible complex interactions, giving rise to feedback phenomena. Such effects can be more precisely assessed via operative models based upon the quantitative representation e.g. of the type shown in Table 2. Quantitative representation does not necessarily mean "crisp numerical" - since very often it is not possible to give unique, reliable numbers. Thus, one has to deal with data of "uncertain", i.e. non-unique, nature.

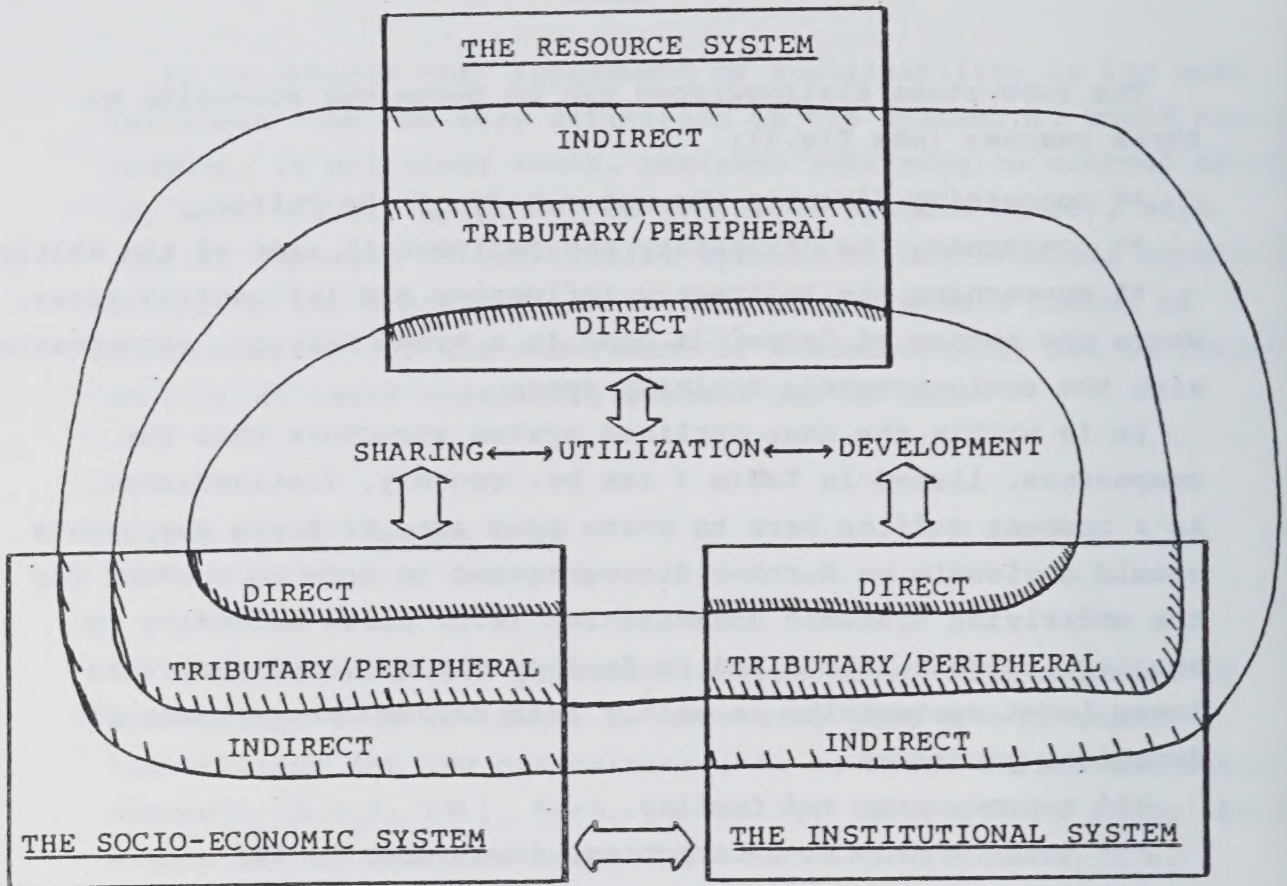


Fig.1 Subsystems and their interactions together with distinction of the three spatial reaches.

The two integration examples indicated in Fig.2 are, roughly, as follows:

1. (The apparently simpler case). In case proper international agreements are not reached on the fish catch quotas for particular countries (and even, though this seems of less probability, when such agreements are concluded and kept to) there exists a high risk of serious overcatch, which may significantly lower future catches. Two questions arise: first, of adequate modelling of fish population dynamics including catches, and second, of preparation of instruments for conducting negotiations taking into account dynamics of payoffs. These questions are also treated in the present set of papers.

REACH TYPE OF RESOURCE	DIRECT	TRIBUTARY / PERIPHERAL	INDIRECT
1. AREA	SEA SURFACE	SHORELINE (LENGTH)	BASIN/COUNTRY
2. WATER	SEA WATER	RIVERS & SEASIDE WATERS ADJACENT SEAS	OTHER BASIN RESOURCES
3. AIR	OVER-SEA BASIN	LOCAL WINDS	REGIONAL WINDS
4. LAND	SEA-BED	SHORELINE (QUALITY)	LAND-USE, STRUC- TURE, SOILS
5. BIOTA	FISH AND OTHER SEA BIOTA	SEASHORE VEGETATION COVER AND ANIMAL WORLD	INLAND FOREST & AGRICULTURAL LAND
6. PEOPLE	SEA-BOUND PO- PULATION	SEASIDE POPULATION	BASIN/COUNTRY POPULATION
7. INFRA- STRUCTURE	WATERWAYS, PORTS	LEISURE, MUNICIPALITIES, COASTAL TRANSPORT	INLAND DENSITY VS. SHORELINE
8. PRODUCTIVE ASSETS	DIRECT EXPLOI- TATION	SEASIDE INDUSTRIES	RELATED INLAND INDUSTRIES
9. SCIENCE	MARITIME SCIENCE INSTITUTIONS	SEASIDE SCIENTIFIC CENTRES	COUNTRY'S POTENTIAL

Table 1. Components involved in the natural resource and ecology subsystem, as well as in the socio-economic subsystem

2. Industrial gaseous and particulate emissions cause directly air pollution, but through complex chemical reactions form compounds directly and indirectly influencing water and soil resources, and thereby plants - in particular forests. The questions to be clarified are contained in one: what is the mechanism of - e.g. - forest decline under the influence of air pollution with special consideration of: various types of decline and processes behind them, and consequences as well as silvicultural countermeasures (see Owsinski, 1987) so that the whole chain, including economic and managerial feedback, could be uncovered, analysed and properly managed. These questions are insofar hard to solve and even address as there are still important lacunae in the knowledge concerning damage from air pollution.

Fig.2 emphasises the "model" side of the overall domain. This is insofar important as every human action is based upon a perception of reality constituting in fact "models", be it verbal, fuzzy and implicit or numerical and uniquely, explicitly defined. The procedure always works according to the scheme of Fig.3 (Owsinski and von Winterfeldt, 1976), accounting for an illustration proper for our case.

Such a procedure as the one shown in Fig.3 can be understood in two main manners: first, as a cyclic process with continuous time, mainly implemented through exercise of management, wherein specialized functions are implemented, involving, hypothetically a constant use and update of models, whether of purely verbal and qualitative or of quantitative, numerical kind. The second meaning of this procedure is its recursive deployment, like in model development, experiment design, prototype and test item execution, prior to full-scale production. In both cases model design development, update and use plays a crucial role.

Table 2. Framework for studies on intercomponent relations.

COMPONENTS AND INTERRELATIONS Resource, Ecology, Economy	1. SEA SURFACE SEABED	2. SHORELINE LENGTH	3. BASINS /LAND/	4. SEA WATER	5. RIVERS AND ADJACENT SEAS	6. BASINS	7. OVER-SEA	8. LOCAL WINDS	9. REGIONAL WINDS	10. FISH	11. SEASIDE	12. FORESTRY + AGRICULTURE	13. SEA-BOUND POPULATION	14. SEASHORE POPULATION	15. BASIN POPULATION	16. WATERWAYS PORTS	17. LEISURE MUNICIPALITIES, TRANS-PORT	18. INLAND	19. DIRECT EXPLOITATION	20. SEASIDE INDUSTRIES	21. BASIN INDUSTRIES
1. SEA SURFACE	*																				
2. SHORELINE LENGTH																					
3. BASINS /LAND/																					
4. SEA WATER																					
5. RIVERS AND ADJACENT SEAS																					
6. BASINS																					
7. OVER-SEA																					
8. LOCAL WINDS																					
9. REGIONAL WINDS																					
10. FISH																					
11. SEASIDE																					
12. FORESTRY + AGRICULTURE																					
13. SEA-BOUND POPULATION																					
14. SEASHORE POPULATION																					
15. BASIN POPULATION																					
16. WATERWAYS PORTS																					
17. LEISURE MUNICIPALITIES, TRANS-PORT																					
18. INLAND																					
19. DIRECT EXPLOITATION																					
20. SEASIDE INDUSTRIES																					
21. BASIN INDUSTRIES																					

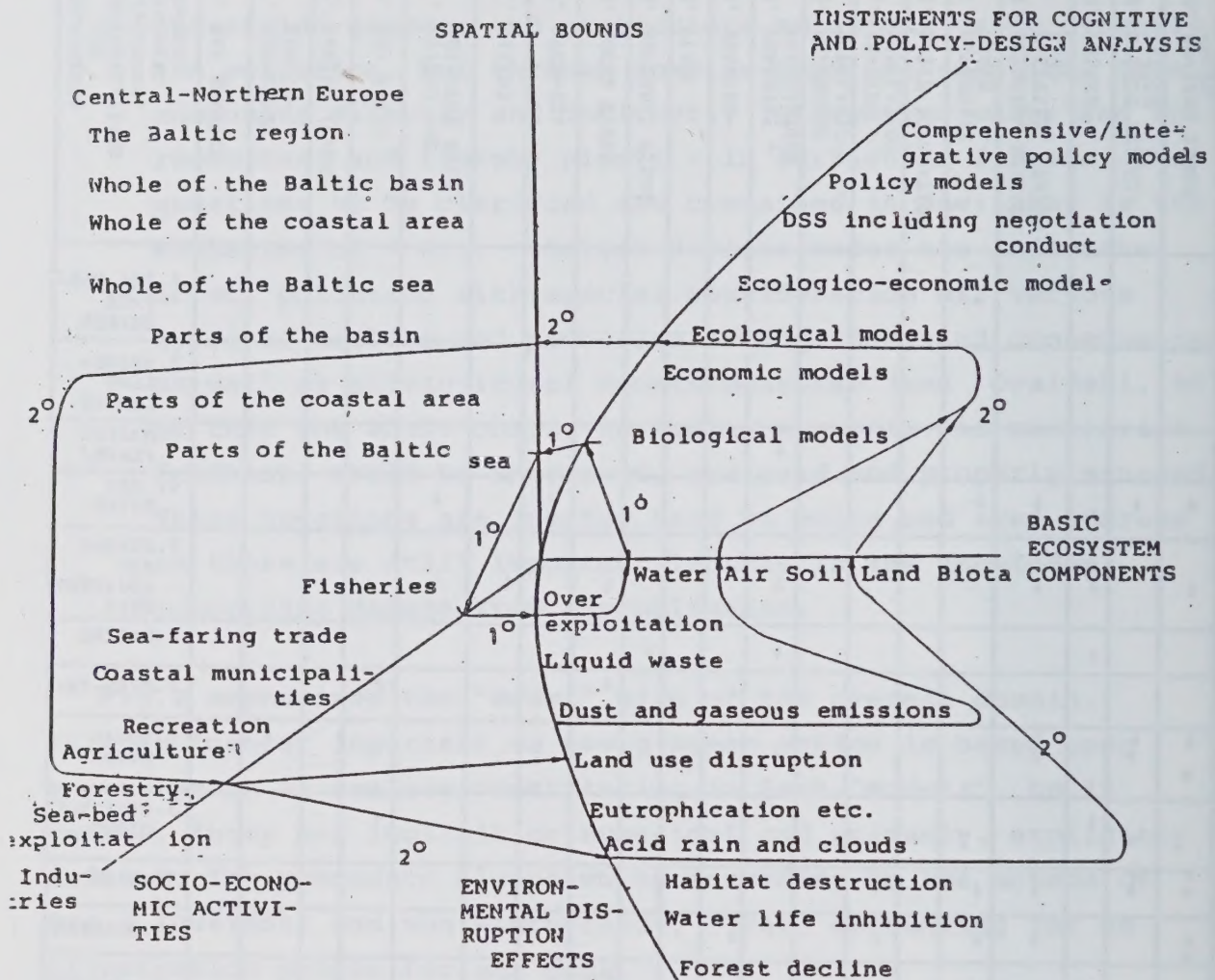


Fig.2 Dimensions appearing in definition of the boundaries of a regional system and in the assessment of sustainability, after Kajriukštis and Espejo (1986). Modified for the Baltic case, with illustrations for causal interdependence chains. Comments in the text.

It is proposed in this paper that in such complex dynamic multi-aspect systems as the one - potential - considered here it is not possible to take senseful actions without adequate formalization - preserving possibly all flexibility - of perceptions as well as objectives. This, again, can be illustrated with Fig.4 and 5, representing partial interactions and referring to notions introduced in Table 2. Although these diagrams are relatively

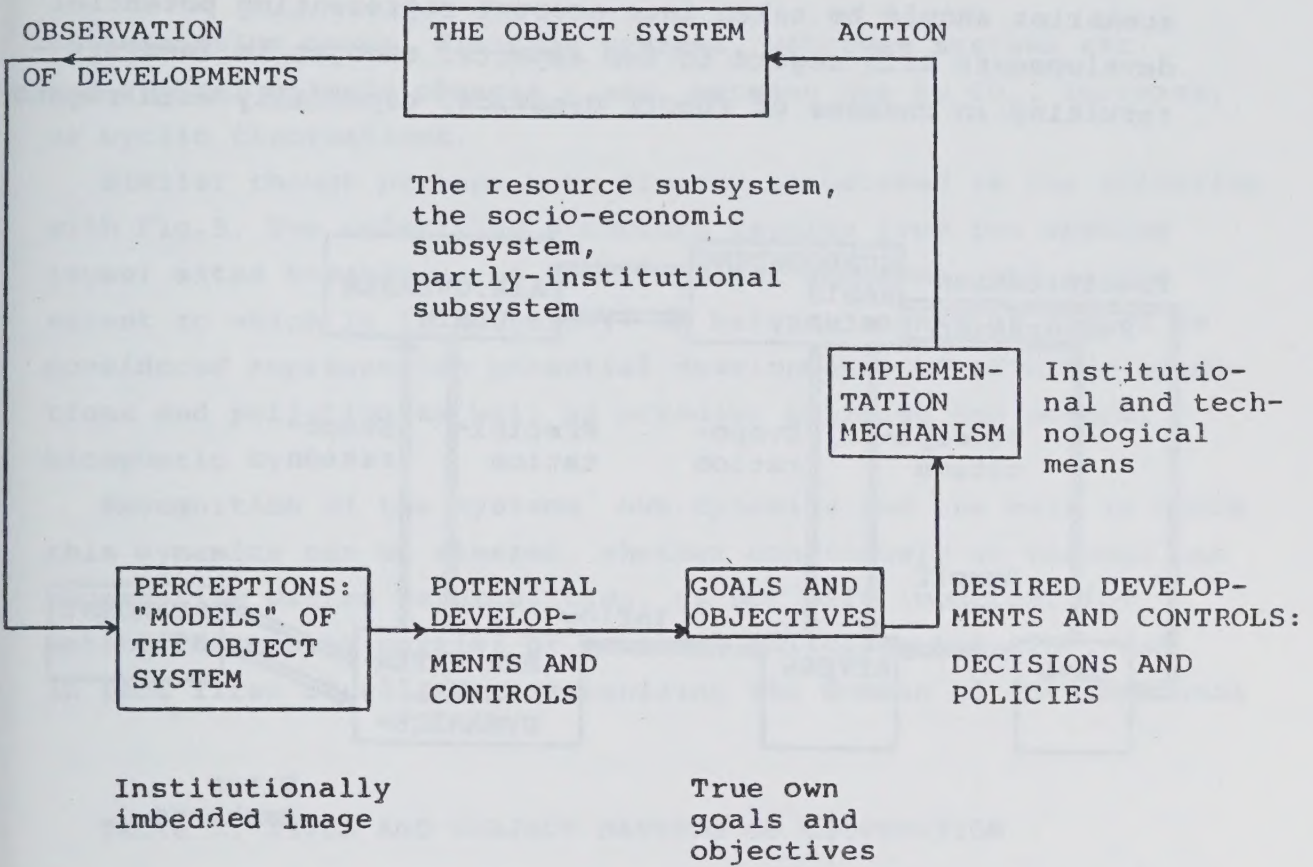


Fig.3 General scheme of decision/policy making, involving use of perceptions or "models".

rough, they illustrate sufficiently well, it seems, complexity of even very partial interaction segments. Note, especially, with reference to Fig.4, that blocks appearing there (RIVERS, LAND,...) are in fact to be seen as composed of separate subblocks, even if at a some level of aggregation. Moreover, analysis should be performed for a variety of differing weather condition scenarios stretching over several-year periods. It is obvious that analytic solutions are not to be reached presently, so that a series of complex simulations should be performed with parallel computation of corresponding estimates of probabilities of occurrence of conditions appearing in a given simulation. On the top of that

scenarios should be taken into account representing potential developments with regard to two aspects: changes in land use - resulting in changes of runoff dynamics, especially with regard

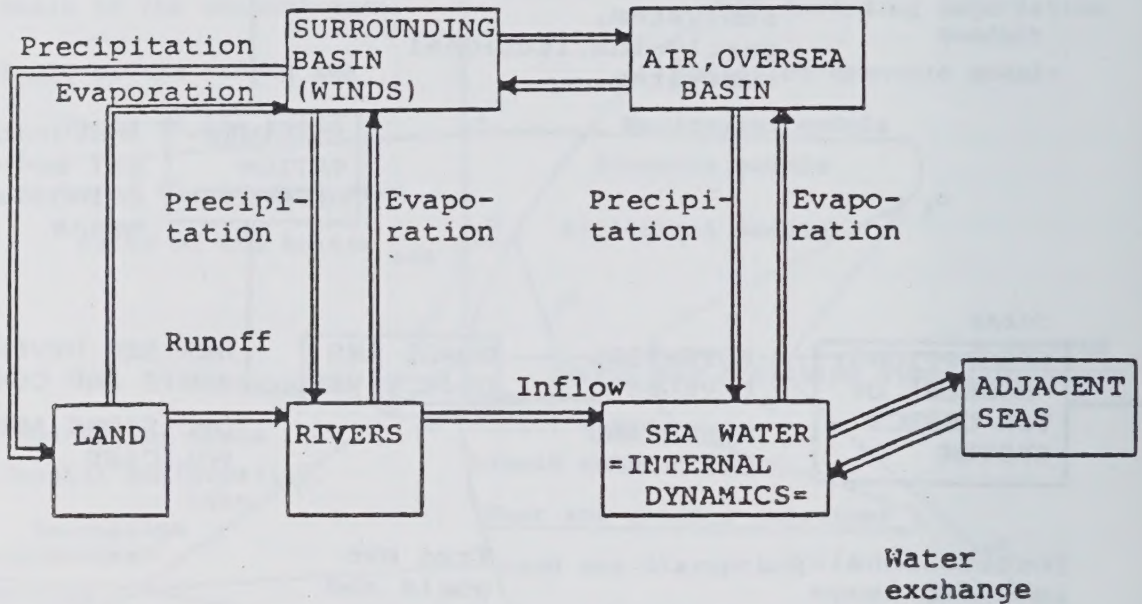


Fig.4 Water cycle: macroview. Analysis should involve such aspects as: oxygen supply and demand, pollutant dynamics etc.

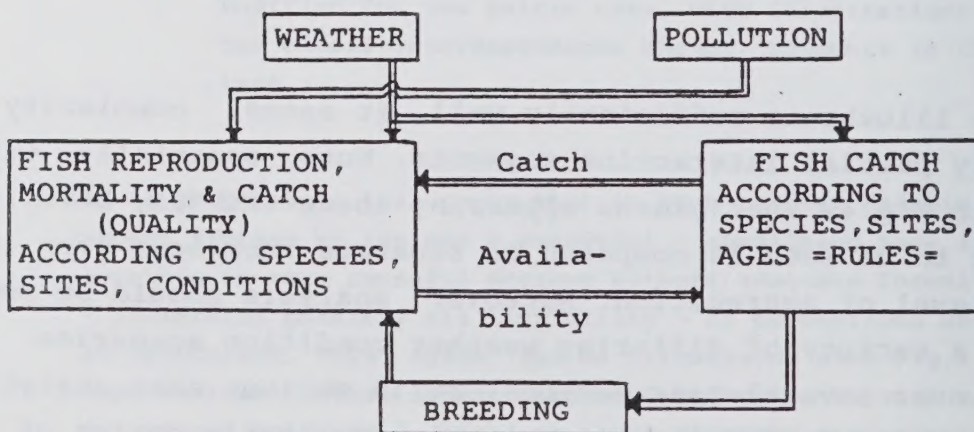


Fig.5. The fishery interaction segment: macroview.

to vegetation cover, drainage systems, waterway systems etc., and general climate changes - say, warming due to CO_2 , increase, or cyclic fluctuations.

Similar though perhaps more clearly structured is the situation with Fig.5. The underlying structure results from the species (ages) sites breakdown, at least applied whenever, and to the extent to which it is necessary. As before, scenarios should be considered representing potential developments of climatic conditions and pollution as well as breeding policies and general biospheric cycles.

Recognition of the systems' own dynamics and the ways in which this dynamics can be steered, whether consciously or through not necessarily wanted externalities, as not only important for making reasonable partial or national policies, but also, and in fact first of all, for recognizing the domain of international

Table 3. TYPES AND SUBJECT MATTERS OF COOPERATION

SEA SURFACE AND SEABED DIVISION

WATERWAY AGREEMENTS

FISHING AGREEMENTS

POLLUTION AGREEMENTS

SEABED EXPLOITATION CONTRACTS

SEABORNE TRANSPORTATION

COMMON FISH RESOURCES POLICY AND UNDERTAKINGS

COMMON POLLUTION ABATEMENT POLICY AND UNDERTAKINGS

INTRA-REGIONAL TRANSPORTATION SHARE

INTRA-REGIONAL TOURISM AND RECREATION SHARE

INTRA-REGIONAL TRADE SHARE

INTRA-REGIONAL CAPITAL ASSETS MOVEMENT SHARE

cooperation (share) negotiations, whose results largely determine the rationality of the national policies. In accordance with the indications of Table 2 the list of potential, and to a large extent also actual, subject matters and forms of cooperation agreements and related negotiations, is shown. Note, again, that particular agreements are objectively related through dependencies shown partly in Table 2, which should be subject to more precise analysis and modelling. Obviously, only with adequate information agreements can be reached which would with be reasonable and not too vulnerable to disruption. Things unavoidable are better met when prepared for in advance.

When assessing "objective" - natural resource - systemicity it becomes also necessary to look into matching i.e. all-englobing systemicity, by the socio-economic and institutional subsystems. The intention is not to propose any particular bodies, even less a "Baltic government", but rather - in view of existing systemicity and existing institutional setting, primarily common commissions with, first of all, Helcom - to assess mutual correspondence, and adequacy to the mutual contact and information needs of the societies.

3.2. Illustrations

In line with the introductory considerations a few illustrations given here are meant to provide an idea as to the degree of closure of the Baltic Region with regard to certain aspects. In fact, if we were to follow more closely the substance matter and the procedure proposed, we would have, consecutively, to ask for the closure with respect, first, the natural resource subsystem components, and only then with regard to the components of the socio-economic subsystem and of the institutional subsystem. Thus, Table 4 and Fig.6 present just a very partial view, though of at least approximately quantitative nature. Not going further in this direction one can easily see that with respect to the natural resource subsystem there is a great degree of systemic closure. Therefore, the opportunity arises of using the area as the pilot one for the European climate study, see Munn (1987).

Table 4. Some features of the "elements" of the Baltic Region (countries, areas)

Features Coun-tries, areas	1.Area, 10 ³ sq km	2.Population 10 ⁶	3.Coastal line length*1	4.Coastal coeffi- cient*2	5.Population coeffi- cient*3	6.Port activity 10 ⁶ tons
1. Denmark	40.0	5.1	~4000	20.0	2300.0	38.9
2. Sweden	450.0	8.4	~2500	3.73	70.9	82.4
3. Finland	335.2	4.9	~1100	1.90	28.5	54.9
4. USSR-Leningrade	85.9	6.5				
5. USSR-Estonia	45.2	1.6	~1240	5.83	198.2	
6. USSR-Latvia	63.7	2.6				
7. USSR-Lithmania	65.2	3.6				
8. USSR-Kaliningrade	15.1	0.9				
9. Poland	311.8	38.0	524	0.94	114.5	50.6
10. German DR	109.3	16.6	~400	1.21	186.3	26.0
11. Germany, FR	246.8	59.2*4	313*4	0.63	149.6	54.0
Totals	1770.0	147.4	~13000	~2.95*	~245.7	-

Explanations: *1 approximation, *2 excluding smaller islands: ratio of the sea-coast length to square root of surface R, *3 population density x R, *4 note that FR of Germany borders also with North Sea

Country Country	Denmark	Sweden	Finland	USSR	Poland	GDR	FRG
Denmark		xxxxxxx	xxx	x			xxxxxxx xxxxxxx
Sweden	xxxxx		xxxx	xxx	x	x	xxxxxxx
Finland	xx	xxxxxxx		xxxxxxx xxxxxxx	xx		xxxxxxx
USSR			xxxxx		xxxxxxx	xxxx xxxx	xxxxx
Poland							
GDR				xxxxxxx xxxxxxx xxxxxxx	xxxxx		xxxx
FRG	xxx	xxxx		xxxx		xxx	

Fig.6. Scheme of trade relations (approximate).

Entry (i,j) demotes the share taken by country j in the trade volume of country i.

Systemic closure, though, as indicated before, should not only be looked for within the separate components, but also at their interrelations. It is also the internal strength of these relations that contributes to systemicity. An illustration for that is provided by means of Table 5. Pluses and minuses appearing as entries should be understood in the economic sense, that is - increased profits by increased returns or decreased profits by additional costs or decreased activity levels. As can be seen the table is almost entirely covered by essential relations.

Ending these few examples is Table 6, showing qualitative assessment of systemic closure with respect to particular components and their interrelations. Some comments on the contents of Table 6, as for Table 4, anyway, are necessary. Let us start with Table 4. Important role in this table is played by the coastal coefficient R. In fact, denoting country number by i, we may set, in accordance with notations from section 2.1. of this paper

TYPE OF POLLUTION-RELATED ACTIVITY TYPE OF ECONOMIC ACTIVITY	DECREASE OF POLLUTION IN POLLUTION ABATEMENT IN					
	COASTAL MUNICIPALITIES	COASTAL INDUSTRY	PORTS	MARITIME TRANSPORT	RIVERS	INLAND INDUSTRIES
SEASIDE TOURISM & RECREATION	++	++	++	+	+	+
FISHERY	++	±	±	±	+	+
MUNICIPAL ECONOMIES	±	±	±	±	±	+
SEABED EXPLOITATION		-	-	-		
TRANSPORTATION			-	-	-	
COASTAL INDUSTRIES	+	- +	+		+	

Table 5. Impacts of pollution decrease policies.

$$s_{i.} = \sum_{j \neq i} s_{ij} = R_i \quad (6)$$

and

$$S(A_q) = \frac{1}{\text{card } A_q^-} \sum_{i \in A_q} s_{i.} \quad (7)$$

For comparison with numbers appearing in Table 4 for R_i note that R takes the value of 1.0 in case of a square country with one side of the square being sea wast (the considered sea's coast), and 3.14, i.e. Π , in case of a circular island. Thus, significance of the sea for the regional system of the coastal countries increases with $S(A_q)$. Now it is possible either to set a threshold value for $S(A_q)$, necessary for qualification of A_q as a system, or to properly define the function $S(A,B)$ in order to apply the

criteria (1), (2), (3). The threshold value seems to lay well below 1.0 (the value of 0.5 is obtained for a country 2×8 whose shorter side is a coast) and therefore, according to (7), A_q would encompass all the Baltic countries. Another measure of "natural systemicity", leading to determination of S_{ij} and $S(A,B)$ would involve distances across the sea, but this does not seem necessary here because of relatively small dimensions of the sea and limited number of countries considered (such a measure would be proper for a bigger sea, an ocean or its-part). Still another type of criterion might be related to overlapping of countries with the given sea's water basin. In this case results for the Baltic Region will be equally convincing as the ones here shown.

Countries, though, may enter socio-economic systemic relations even if no, or little, natural prerequisites exist, see the case of the Northern Atlantic and of the Pacific. Trade is one of the expressions of that, see Fig.6 This indicator, though, should also be looked at against the background of certain propensities, some of which one shown in Table 4.

Thus, qualitatively, the degree of closure with regard to various components and their interactions as assessed by these authors is given in Table 6. Note that the naturally conditioned systemicity is not matched by the corresponding socio-economic and institutional ones. Appropriate match, see e.g. Fig.6, exists only between certain country pairs and subsets. Hence, existing natural potential is not fully used and to the extent to which it is oriented in other directions this may even lead to definite opportunity costs, as can be seen through pollution effects as well. This may constitute the basis for defining $Q(A_q)$ on the basis of q_{ij} which would represent such (negative) costs for bilateral relations or of q_i , representing these (negative) costs for one country. Thus, since q_{ij} and q_i would be largely determined with the help of the "natural" systemicity levels, obtained for the resource components the function $Q(A_q)$ can be represented through $Q(S(A_q))$, of different form, of course.

Obviously, socio-economic systemicity would require more of trade connections, common undertakings, tourist movement, but also information flow and scientific exchange and cooperation.

Existence of proper horizontal ties would ensure proper functioning of the potential vertical - intra-country or international institutional mechanisms. Without too detailed suggestions one might imagine also a sort of knowledge centres where, e.g. common assessment of the regions state could be made or particular policy roles (or even policies themselves) would be tested jointly.

4. Sustainability

If we agree to the statement that the Baltic Region is essentially a true region from the point of view of natural resources - but also their disruption, and that therefore it is, potentially, a true region from the socio-economic and institutional points of view, the question of sustainability acquires a new dimension: that of requisite variety. First, it is necessary to establish the measures (indicators) of sustainability, that is, $\{x_{lk^*}, l \in I, k^* \in K\}$; or, in fact, just $k^* \in K$, then to establish its - systemic - links with other parts of the system, and finally to try to establish conditions for sustainability in accordance with definitions adopted in 2.2.

In the two sections of this chapter more detailed questions pertaining to measurement and preservation of sustainability are discussed. Here only one remark of general nature shall be forwarded. It has been accepted throughout this paper, without, almost any justification that countries or their proper parts can be treated as elements of the hypothetical regional system. Justifications cited concerned primarily the very fact of systemicity, but note that they were based upon countries as elements. Thus, it becomes self-evident to adopt countries as elements, at least at the first level of disaggregation. Sustainability, though, shall refer to more detailed questions. Let us treat them as "features" of these elements.

Component or Interaction	Reach		
	Direct	Tributary/ Peripheral	Indirect
Water	x	/	
Air	/	/	/
Land (use)	/	/	
Biota	x	/	
People	/		
Infrastructure	x	/	
Production	/		
Science	/		
Water pollution	x	x	
Air pollution	/	/	/
Transportation	x	/	
Trade	x	/	
Institutions	/		

Table 6. Assessment of systemicity. x - tightly connected system, / - loosely connected system, void - below the systemicity threshold.

4.1. Sustainability indicators

The magnitudes x_{lk}^* chosen as indicators should satisfy simultaneously two conditions:

- * they should be able to represent in an aggregate way the state of the system, through its crucial features, and
- * to be relatively simple intellectually and, if possible, observationally.

It is obvious that these two conditions may easily turn out contradictory. Thus, it may be proper to start with ensuring satisfaction of the first condition through proposition of an aggregate measure or measures, and then work back to simpler, partial indicators forming and/or conditioning the aggregate one or ones.

Thus, let us propose as the aggregate measures:

1. "Reproductive capacity level of the ecosystem", and
2. "Personal consumption level",

so that these two have, over time, to be reconciled, without the necessity of forcing the direct commensurability. Note the quotation marks: they emphasize the very general nature of the two.

4.1.1. Reproductive capacity level of the ecosystem

Since we are to look at this capacity over a, practically, infinite time horizon ("in the long run we are all dead") the ways of assessing it a priori must be chosen very carefully. They may in fact differ from the methods of a posteriori estimation, used in controlling of actual development. The latter might in theory be done "by force", by evaluating the state of particular parts of the Baltic Region ecosystem, in some cases even down to the level of species, though mainly based upon the geographic, land use and ecological divisions. It is obvious, however, that such a process, though it may be necessary to undertake, would not only be cumbersome, but also at risk of important estimation errors.

Because of all this, one has to use a set of proxy indicators in the a priori assessment. These indicators, while oriented at ensuring of the proper levels of the Reproductive Capacity measure, should preserve relative simplicity in a posteriori assessments and a possibility of forecasting through their relations to other components of the system. More precise definition of these partial indicators would constitute a subject for separate research, but a suggestion can already be forwarded:

- 1.1. dynamics of populations of the more sensitive species of biota,
- 1.2. dynamics of a definite function of specific pollution levels in a set of locations,
- 1.3. shares of particular land uses over time,
- 1.4. population health indicators related to state of environment.

All of these indicators should be analysed, forecasted and observed taking into account natural fluctuations in the environment and potential natural secular trends in the environment. Some comments on these indicators are given below:

1.1. A choice of biological populations should be made, which could then serve as the vector indicator, provided populations are adequately sensitive to environmental conditions, their number is not too high (up to 10), and they are not too close to extinction. Note that these requirements do not specify whether indicator populations should be small and ultimately threatened by extinction or great and ultimately threatening other competitors, but certainly these two types should be, parallelly taken into consideration. A suggestion of seal population in the Baltic for an indicator is, for instance, forwarded in this volume.

1.2. Quite a complex choice should be made concerning: types of pollutants (elements and compounds), locations, environments for which pollution levels shall be considered, as well as pollution levels themselves. . In order to preserve measurement simplicity as well as "forecastability" there should just be: three to four polluting components (say, related to sulphur, nitrogen and heavy metals), at most two locations in each country considered (but not less than one), and one location in each of the essential parts of the coast and the sea (not more than altogether ten), and on the other hand, at least altogether three locations per type of environment - maritime, inland water, air, agricultural soil, forest soil. Note that this does not anyway set additional requirements on the existing monitoring systems, since they are - and justly - much more comprehensive. The choice here mentioned should be made mainly for focussing of attention on crucial aspects and locations, and for purposes of forecasting and its reassessment. The choice of levels concerns primarily the kinds of measurements to be then evaluated (averages? maxima?...) and their relation to models.

1.3. It is assumed that certain developments of land use structure are inconsistent with the overall reproduction capacity criterion. This concerns, for instance, forest shares and

their dynamics, or shares of land under urban or industrial uses, see Table 7. For each subarea (or country) the forest shares compared with forest quality (type, age, health) should be tracked.

1.4. Health indicators should be chosen to account for the impact of environmental changes. Since medical qualifications in various countries may differ the effort should be oriented at: establishment of a unified qualification and choice of best suiting medical indicators, with dynamics being looked at for each country separately. A suggestion for indicators may include: frequencies of allergic diseases and of certain forms of cancer, as well as contents of certain chemical elements in some human organs. Note that the other side of the human-related indicators is contained within the aggregate measure 2., i.e. "personal consumption level", and since it is the human beings who, through their acceptance, constitute the ultimate yardstick of the development, the two have to be balanced, which implies not only proper physical and material, but also spiritual well-being

COUNTRIES	Land use shares %				Persons per sq km of forest	Fertilizer per wheat yield, kg/q
	1. Forests	2. Arable lands and orchards	3. Perma- nent grass- lands	4. Totals 1-3		
1. DENMARK	12	60	7	79	1024	3.9
2. SWEDEN	59	7	2	68	32	3.9
3. FINLAND	69	7	1	77	21	7.2
4. ESTONIAN SRR	43	33	22	98	82	9.0
5. LATVIAN SRR	42	27	12	81	96	9.7
6. LITHUANIAN SRR	28	37	18	83	200	9.3
7. POLAND	28	48	13	89	432	7.1
8. GERMAN DR	25	46	12	83	620	7.4
9. GERMANY FR	29	30	19	78	820	7.6

Table 7. Some indices of land use and its intensity

4.1.2. Personal consumption level

Because of incomparable national product accounting systems in various countries it is much more appropriate to look at the simple physical per capita measures such as:

- 2.1 number of passenger cars per 1000 persons in the age bracket of 18 to 65 years;
- 2.2 number of telephones per 1000 inhabitants;
- 2.3 flat area per 1 inhabitant;
- 2.4 health care indicators, involving diet composition, numbers of hospital beds per 1000 persons, life expectancy and infant mortality.

It is only an apparent paradox that these indicators while much simpler to measure and to determine, are, as to their values, much more difficult to forecast than the one oriented at ensuring the reproductive capacity. Still, they have to be kept for both these reasons.

4.2. Sustainability: its role and preservation

Sustainability is a condition set on development trajectories. It can be set on the trajectories of regional development insofar as regions are true ecological and socio-economic systems. As is known from the theory of mathematical programming, goals and constraints (conditions) can be interchanged as to their role in the system representation. Thus, one may either speak of attainment of socio-economic development objectives under constraints set via conditions on the development's sustainability, or of attainment of "maximum" sustainability under condition of "adequate" satisfaction of population needs. It can easily be seen, though, that the second version, from the point of view of both substantial contents and of present knowledge, is infeasible. First, though it seems rational to try to assess the

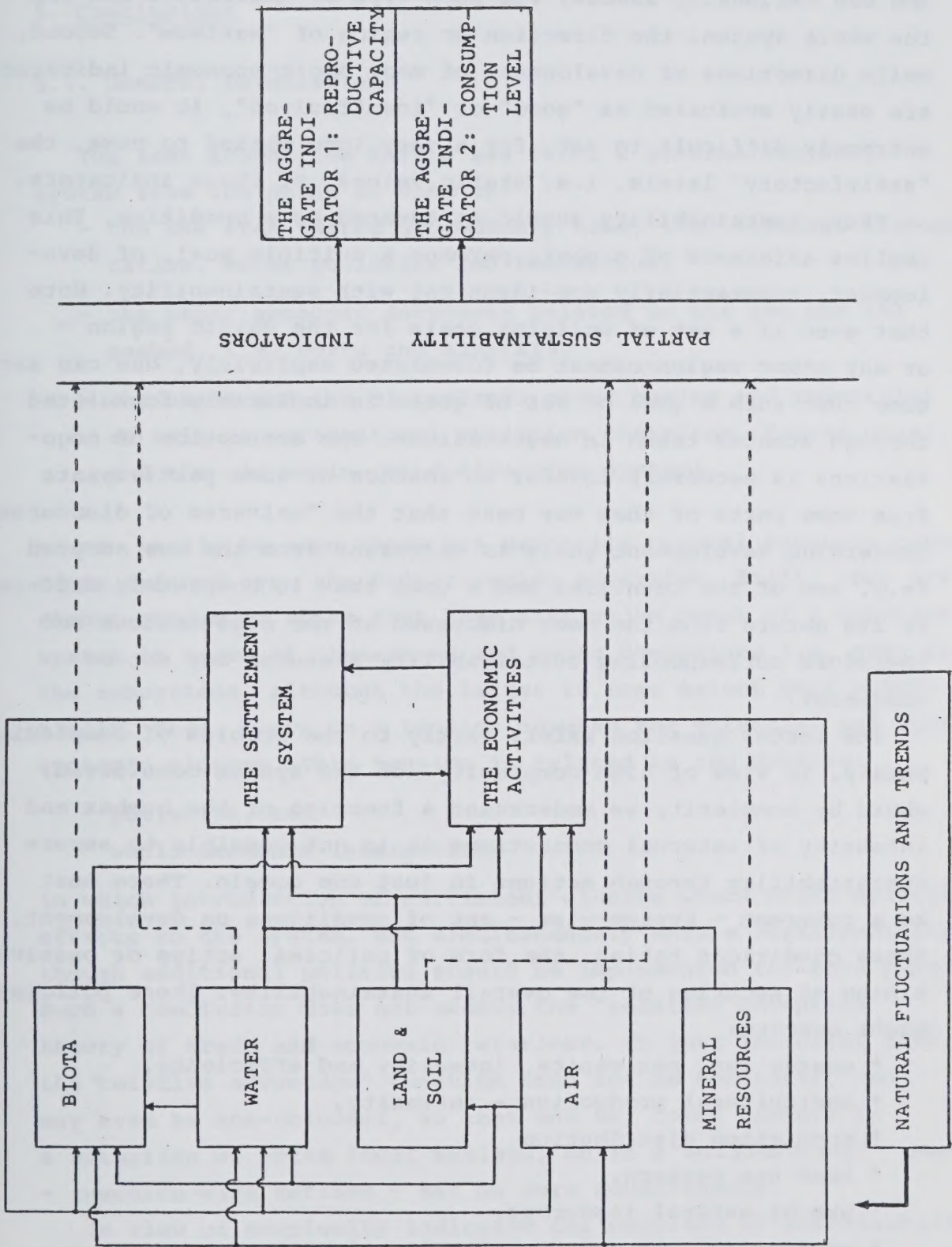


Fig.7 Consumption and pollution relations of the resource and socio-economic subsystems with regard to sustainability indicators

outer limits of sustainability, e.g. via models involving the sustainability indicators listed, it is quite doubtful whether one can rationally assess, via such type of indicators and for the whole system, the direction or region of "maximum". Second, while directions of development of many socio-economic indicators are easily evaluated as "good" or "insufficient", it would be extremely difficult to set, for a very long period to come, the "satisfactory" levels, i.e. static values, of these indicators.

Thus, sustainability should be treated as a condition. This implies existence of a goal, perhaps a multiple goal, of development, substantially non-identical with sustainability. Note that even if a set of unifying goals for the Baltic Region - or any other region - cannot be formulated explicitly, one can assume that such a goal or set of goals is implicitly formulated through stances taken in negotiations. The assumption of negotiations is necessary insofar as absence of some participants from some parts of them may mean that the "universe of discourse" concerning development goals is different from the one adopted (e.g. one of the countries has a goal that is completely different in its nature from the ones discussed at the negotiations and therefore corresponding sustainability measures may not be adequate).

The latter question refers partly to the problem of complexity. Namely, in view of high complexity of the system considered, where by complexity we understand a function of the number and intensity of internal connections it is not possible to secure sustainability through actions in just one domain. There must be a coherent - system-wise - set of conditions on development, these conditions taking the form of policies, active or passive, aiming at securing of the overall sustainability. These policies might concern:

- * energy use, per capita, intensity and efficiency,
- * agricultural production - intensity,
- * population distribution,
- * land use pattern,
- * use of natural resources,
- * production, use and distribution of wastes.

Some comments on these will be offered in the following, concluding section.

5. Conclusions

5.1. General formulations

The area around the Baltic sea forms a genuine regional system from the point of view of:

- the sea area shared or commonly used, i.e. fishing, transportation, water pollution and recreation,
- the other economic interests related to the sea and the seabed, i.e. ports and minerals,
- the basin and the hinterlands river basins and industrial as well as agricultural pollution therefrom, forest cover, and the air basin (wind direction system).

As can easily be seen these are primarily natural resource connections defined over the Baltic region ecosystem. Still, they are strong enough to state that they suffice to speak of a coherent system in terms of themselves and among themselves i.e. over all the subsystems, although the latter to some extent only potentially. Thus, there is a tension between the potential and current systemic closure. This tension is related to two domains:

- * pollution, and
- * socio-economic interactions

in which introduction of sufficient closure would bring synergetic effects to the system, and simultaneously ensure sustainability, though additional policies should be implemented for this purpose. Such a conclusion does not negate the "relative advantage" theory of trade and economic relations. It just indicates that the "relative advantage" function need not be monotonic, and may even be non-unimodal, so that one may find himself in a situation of worse local maximum, while a "neighbouring" one - resource-wise defined - may be more advantageous.

In view of complexity indicated the problems of sustainability cannot be solved within particular domains, e.g. the ones mentioned above. They should rather be solved within an englobing systemic

framework of regional development and own dynamics. This framework should account for potential conflicts and should be directed towards certain global objectives.

On the other hand development cannot be perceived and designed per se, so that the main conditions for development towards whatever objective must be kept to over the whole trajectory. These conditions involve, besides sustainability, also internal consistency. Thus, it can be said that smooth development requires comprehensive - with regard to system components, and integrative - with regard to their interconnections, analysis and planning. In view of the complexity involved it is necessary to try to rationalize analysis and decisions through, first, development and use of models and, second, application of decision and negotiation support tools.

5.2. Specific suggestions

The systems and operational sciences are capable of providing instruments mentioned in the last paragraph. Thus, first, suggestions are provided for the nature of such tools, then for their subject matters and finally for decision types to be accounted for:

Instruments:

- * models for particular components and subcomponents (e.g. fish population models, forest growth models, pollution transport, particular economic activities, branches or sectors),

- * aggregate models (ecological models, models of economy, economic-ecological models, balancing schemes, emission-and-impact models),

- * decision and negotiation support tools (multiobjective techniques, multiperson gaming applications, games, preference aggregation techniques, negotiation applications),

Questions to be answered:

- * dynamics of particular components and subsystem parts in dependence upon: fluctuations of general natural environment conditions, policies implemented and other exogenous not yet endogenizable, factors;

- * dependence of the sustainability indicators upon the developments in particular components and subsystems;

- * reconciliation of the sustainability indicators among themselves and with the development goals.

Policies to be assessed:

- * land use shares - protective minimum shares, e.g. with regards to forests surrounding the Baltic sea,
- * pollution emission and control policies and agreements,
- * fertilizer and pesticide use control in agriculture,
- * nuclear emission and waste control in the basin,
- * fishing quota agreements,
- * seabed exploitation agreements,
- * common economic and technological undertakings e.g. in pollution abatement, recreation, food processing.

With regard to policies there should be a search for: appropriate model instrumentation, and the use of these instruments in determination of corresponding levels, quota. measures etc.

It seems, even looking at the contents of this volume, that there is a potential significant offer of techniques and models which could, at least partly, do the job. There is, then, the task of promoting them in showing consequences of less-than-possibly-rational decision making, of developing them to the policy making stage, and of making a coherent system out of them, corresponding to the object (resource and socio-economic) and to the institutional subsystems of the Baltic Region.

The offer mentioned might be made operational through international scientific cooperation aiming at provision of particular tools and at checking individual policy ideas for the Baltic Region, via the already existing contacts or associations or through the new ones. In the context of cooperation and in view of the systemic prerequisites here shown it seems doubtful whether bilaterality would be sufficient. Why not treat the Baltic Region as a testbed for the coming of Europe? Perhaps the idea of the Baltic Institute for Applied Systems Analysis (BIASA!) is yet too early, but the perspective may be correct in view of cognitive and analytical necessities.

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Ecological and economic models of the Baltic as a whole and the Baltic sea basin

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Abstract. This paper presents results from a combined ecological, economic regional analysis of the Baltic as a whole, including models of adaptation, water quality and energy. Some of the results can be used to assess the impact of various management options on the environment.

ECOLOGICAL MODELLING

The first study is a review of the relationship of the environmental management to economics in the Baltic region. It will be considered at the level of the Baltic sea as a whole and area, which is therefore regarded as a single framework for the following modelling and results comparison.

1. Introduction

It has become increasingly obvious that the environmental impact of economic activities and consumption are highly integrated. Environmental impact factors associated with economic activity and energy consumption require more and more resources to be developed. Depending on which economic system given country will move from, resources are also environmental impact, which in turn affects the economic contribution from each of the countries in the economy. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system.

There has been an increasing scientific interest in the last decade to address problems of the environment. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system. The impact of economic activities on the environment is also a function of the economic planning system and the nature of the economic system.

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ECOLOGICAL MODELLING

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Ecological and economic models of the island of Gotland and the Baltic sea basin.

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Abstract This paper presents results from a combined ecological, economic regional analysis of the island of Gotland, including models of agriculture, water quality and energy. Some of the models can be used to suggest trends or possible optimum solutions for economic development while others were designed to answer particular questions on environmental impact and constraints. From lessons learned during the Gotland study it appears that the relationships of natural resource management to economics in the Baltic region should be considered at the level of the Baltic Sea catchment area, which is therefore suggested as a useful framework for data gathering, modelling and research cooperation.

1. Introduction

It has become increasingly obvious that the problems related to resource use, environment and economics are highly integrated. Environmental disturbances associated with economic activity and energy consumption require more and more resources to be dealt with. Depending on which economic sectors grow, changes will take place in resource use and environmental impact, which in turn affect the potential contributions from natural ecosystems to the economy. This implies complex problems for planners and decision-makers, whose economic planning horizons are very different from the time-scales of natural processes, and whose evaluation criteria seldom incorporate any concern about the sustainability of the life supporting ecosystems.

There has been an increasing scientific interest in the last decade to address problems at the ecological-economic interface by means of systems analysis and modelling as well as by various other approaches [1,2,3]. One example is an eight year research project carried out on the island of Gotland in the Baltic sea, which will be shortly presented in this paper. The intention is to use some of the achievements from the Gotland

study as a starting-point for discussing a systems approach to the ecological-economic problems of the whole Baltic region.

One of the primary aims of the Gotland study was to find some working methods for analysing the complex interactions between a regional economy, its natural resource base and the outside world. By combining various economic and ecological models we analysed the importance of various limiting factors for the island's future development. In particular, energy in its most general sense was used for weaving together the activities of humans and the natural system processes. The energy analysis was not confined to fuels and electricity but included also the energy flows associated with photosynthesis, winds and waves and the hydrological cycle as well as other solar energy based processes in nature.

A comprehensive summary of the project [4] together with a selected number of articles and technical reports focussing on different problems of resource use and environmental impact, are included in the reference list.

2. Description of Gotland's ecological and economic systems

The island of Gotland, situated in the center of the Baltic Sea area, occupies about 3000 km² and has a resident population of 55,000 (17.5 persons per km²). The island consists of a plateau of silurian limestone with a thin layer of glacial soils on top. The natural ecosystems include coniferous and deciduous forests, heaths, mires, lakes and coastal waters. The island's economic system is fairly diversified with agriculture and the food industry together with limestone quarries and cement production generating the major export. Tourism is important with about 300,000 visitors to the island every summer.

Administratively Gotland functions as a county, but is an integral part of the Swedish economy, which gives considerable financial support to the island. Gotland is strongly dependent on steady inflows of petroleum, electricity, goods and services to maintain its structure and function. Almost half of the population and most of the industrial and governmental infrastructure are concentrated in Visby, the main urban center.

Examination of the environmental situation on Gotland pointed at deteriorating water quality, due to salination, nitrate pollution and traces of herbicides, to be the most severe problem. Also the reserves of fresh water are small due to reduced groundwater recharge and rapid surface runoff after large scale drainage and reclamation of land since the middle

of the 19th century. These areas of concern are coupled to energy and economy in many ways. Enhanced energy use, as well as demand for products from activities connected to agriculture will stimulate production in various sectors. This in turn will lead to increased demand for water and impacts on the hydrology of the island due to the use of more fertilizers and water for irrigation.

3. Systems analysis and modeling

From the very beginning, the emphasis of the Gotland project was on a systematic energy analysis of both the human and the natural systems. Understanding the relationship of energy to the functioning of economic systems is important to plan better for shortages or alterations of energy supply, such as a decreased use of fossil energy due to environmental problems or oil price changes. Knowledge of the renewable energy fluxes helped us to evaluate the magnitude of work that nature continuously performs for society, as well as their potential for exploitation through harvesting or utilisation of winds and waves and other alternative energies.

The initial overview evaluation of the energy flows on Gotland (Fig.1) showed the spectrum of renewable and purchased energies to the island. The fixation of solar energy by photosynthesis in terrestrial and aquatic ecosystems was calculated from data on productivity and harvest. The use of imported fuels and electricity in different sectors of the economy were investigated as well as the energy embodied in imported goods and services. These data not only formed a detailed quantitative energy picture of the island, they were also required for parameterizing the various economic and ecologic models that were formulated during the course of our study.

Although it was intentionally anticipated that differential equation models would be used for all modeling efforts, the fact that only certain types of economic data were reasonably accessible prompted us to adopt an input-output formulation for a quantitative representation of the economic system. In general, in the economic model, the region interacts with the rest of the world by exchanging imports and exports and consuming storages of indigenous resources (Fig. 2). Such a model was used to estimate outputs of each sector based on anticipated final demand, to assess the impact on economic output for shortages on inputs such as energy, and to generate economic and resource multipliers. In addition the input-output model served to estimate the total generation of wastes and pollution from the regional activities.

The estimated waste loadings were used as inputs to ecological simulation models for assessing impacts on the environment. After evaluation, these simulation results guided the establishment of environmental constraints on resource use or pollution outlets. Such constraints, together with a common set of socio-economic limiting factors, were used in various types of optimisation models, where different objective functions could be either maximized or minimized. With the optimisation results available, modifications of the economic system could be suggested for counteracting environmental degradation.

3.1 An input-output model for calculating resource use and pollutant generation

Gotland's economy was simplified into 20 sectors for which input-output data for 1975 were collected. The transaction flows among sectors were obtained by interviews with the major enterprises in each sector or from regional authorities [5]. Data on direct resource requirements per unit output from each of the sectors are summarized in table 1. The indirect and total resource use was calculated by means of the input-output model. The results of this analysis clearly showed that sectors such as slaughteries, dairies, and other food industries had large indirect effects upon the use of resources. For instance for each liter of water consumed in slaughteries 3.7 liters of water were spent in other sectors. Tourism had a high multiplicative effect upon the value added but at the same time increased the nitrogen loadings on the environment both directly and indirectly.

3.2 Simulation model for assessing water quantity and quality impacts.

As already mentioned, serious resource and environmental concerns on Gotland are related to the availability of sufficient water and the quality of groundwater, especially with regard to nitrate pollution. Modelling water quality and quantity was therefore especially important for the establishment of environmental constraints on economic growth. A direct link of water to the energy system will arise if imported oil and coal is to be replaced by indigenous energy, such as biomass from energy plantations. These will require extensive levels of irrigation and fertilization with consequent environmental impact. To analyze the relationships between land use and water quality a lumped parameter simulation model was formulated [6]. The model was validated by means of data from a one-year intensive field study of a 60 km² drainage basin, north of Visby in a former mire area [7,8].

The basic model, formulated as a set of differential equations, consists of storages of soil water, soil nitrate, soil ammonium, soil organic nitrogen, plant nitrogen, groundwater, and groundwater nitrate (Fig.3). These storages are affected by external forcing functions and interact with each other through various physical and biological processes such as precipitation, irrigation, evapotranspiration, runoff and percolation to the groundwater. Fertilization increases soil nitrate and ammonium; soil nitrate is affected by nitrification of ammonium and denitrification, runoff, percolation and uptake by plants. The nitrogen in plants is removed by harvesting or finds its way to the organic nitrogen pool, which is also enhanced by addition of manure.

Various kinds of regimes of fertilization and irrigation were tested for different crops and types of soil. Sensitivity analyses were performed to establish the relationship between levels of fertilization and groundwater nitrate concentrations. Based on these results the maximum fertilization rate was set at 97 kg ha^{-1} , which is less than required for intensive energy plantations.

3.3 Regional optimization with emphasis on water constraints.

One example of regional optimization, mainly focussing on the effect of water resources upon Gotland's economy in 1975, will be given here [5,9]. Besides the twenty economic sectors represented in the input-output matrix this optimisation model also included the household sector. The formulation of the model was essentially a linear programming one in terms of the sector outputs. The objective function chosen was to maximize value added associated with production, minus value added attributed to imports in each sector. Various capacity limits were set on resource consumption and output from each sector. Other constraints concerned employment and permitted use of water, fertilizers and fossil energy.

Several simulations were conducted to determine the effect on varying the water constraint upon the value of the objective function, that is the gross regional product (GRP). The results are summarized in Figure 4. As the water constraint is relaxed, production increases, but in a diminishing return fashion; beyond about 7 million m^3 available per year for economic production no increase in GRP occurs. At low levels of water availability, certain sectors like the food industry, the cement production, printing and the tourist sector are virtually eliminated. The ideal market-determined price on water varies between 22 and 28 SEK per m^3 , which is high in comparison with the actual price of 1.2 SEK m^{-3} paid in 1975.

4. Gotland and the Baltic Sea drainage basin.

Water availability and groundwater nitrate pollution have figured importantly in our study of Gotland's ecological-economic system. The extent to which water and environmental quality may become limiting factors for particular economic activities will be decisive for the economic future. For example, water availability and restrictions on the use of nitrogen fertilizers will be significant constraints for the development of high-producing energy plantations to decrease the dependence on fossil energies [10]. With present management regimes substantial amounts of nitrogen are leaking out from land into the coastal waters, thus adding to the eutrophication of the Baltic Sea which may not only affect fisheries but also reduce the value of Gotland's seashores for recreation purposes [11].

It is obvious that Gotland is faced with similar problems of economic and environmental trade-offs as the whole Baltic region. Air-pollution and degraded terrestrial and water resources makes it necessary to investigate ways to cut down and/or restructure agriculture, energy supply systems and other sectors of the economy in almost all European countries. With the increasing dependency between countries through the international trade and the transnational pollution problems in mind, it seems necessary to take a regional approach to these problems, otherwise national investments in ecosystem management and pollution control run the risk of being counteracted by exploitation practices in surrounding areas.

Because water is one of the principal controlling factors in the landscape as well as in human enterprises it stands out as a convenient element around which such regional cooperation could be organized. The most evident boundary for an integrated systems study of the Baltic region would be the drainage area of the Baltic Sea, as already suggested by Serafin and Zaleski [12], who studied trends in population growth energy and resource consumption for this whole region. Other gross measures that need to be monitored over time are the changes in land use, the composition of the economic activities and the exchanges with outside regions.

The total area of the Baltic Sea drainage basin of 1,721 233 km² is divided between seven countries. A comprehensive summary of the environmental statistics of this whole region is already available [13]. The impacts of increased nutrient loadings and accumulation of harmful substances on the Baltic Sea marine environment have since long been investigated both in national and international research programmes. Recent advances in computer modelling of the coupled physical and biochemical dynamics of the Baltic Sea [14] will facilitate the choice of

which parameters need to be most carefully monitored and eventually enforce further restrictions upon the economic activities in the nations concerned. The relevant institutions for recommending such regulations are the Helsinki Commission and the Baltic Fisheries Committee.

The main working scheme of the Gotland study could perhaps serve as a useful templet for designing an integrated study of the Baltic Sea basin. It is true that the restricted size and well defined boundaries of the island of Gotland makes it much easier to investigate and model than the large scale, multinational and economically complex area of the Baltic basin. Nevertheless, the Gotland project included many of the necessary steps that have to be taken in any comprehensive study of the ecological-economic linkages in a geographical region. For a multidisciplinary project of this kind, where many people will be working simultaneously in several countries, the organizational capacity of an international institution like IIASA is almost indispensable. A systems project on the Baltic Sea basin could serve as an important case study in the ongoing work to identify requirements for an ecologically sustainable development in Europe [15].

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FIGURE LEGENDS

Figure 1. Macroview of Gotland's economy showing major money and energy exchanges with the outside world. The energy cost of imported goods and services is embodied energy value. The energy flows are in PJ and the money flows are in millions of Swedish kronor (Data for, 1972), [4].

Figure 2. Organisational framework for analysis of Gotland's economic - ecological systems. To the left is an economic input-output model for estimating resource demands and waste production. To the right is a set of ecological models used to evaluate environmental impacts which could result in a reassessment of economic activity [4].

Figure 3. Water quantity and quality model used for simulating effects of agricultural practices on Gotland by changing rates of fertilization, groundwater withdrawal and irrigation for different crops or energy plantations. Simulation results from this model were used to determine constraint coefficients for nitrogen in the economic model [6].

Figure 4. Results of maximizing value added and changing the constraint on water available for economic activity on Gotland, 1975 [5].

Table 1. Direct and total resource requirements and pollution generation per Swedish krona output, 1975 calculated from input-output data for 1975 [5].

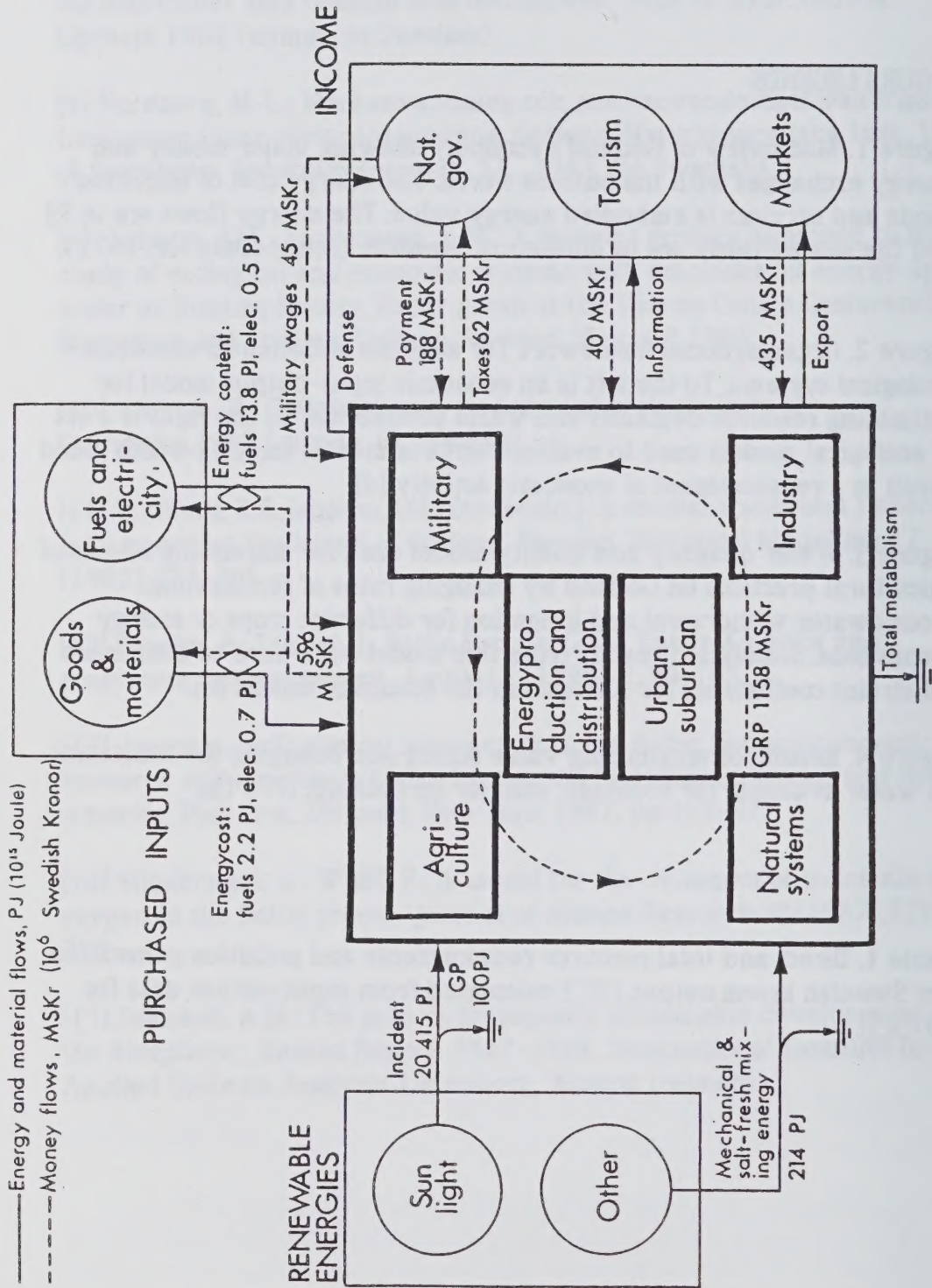


Figure 1.

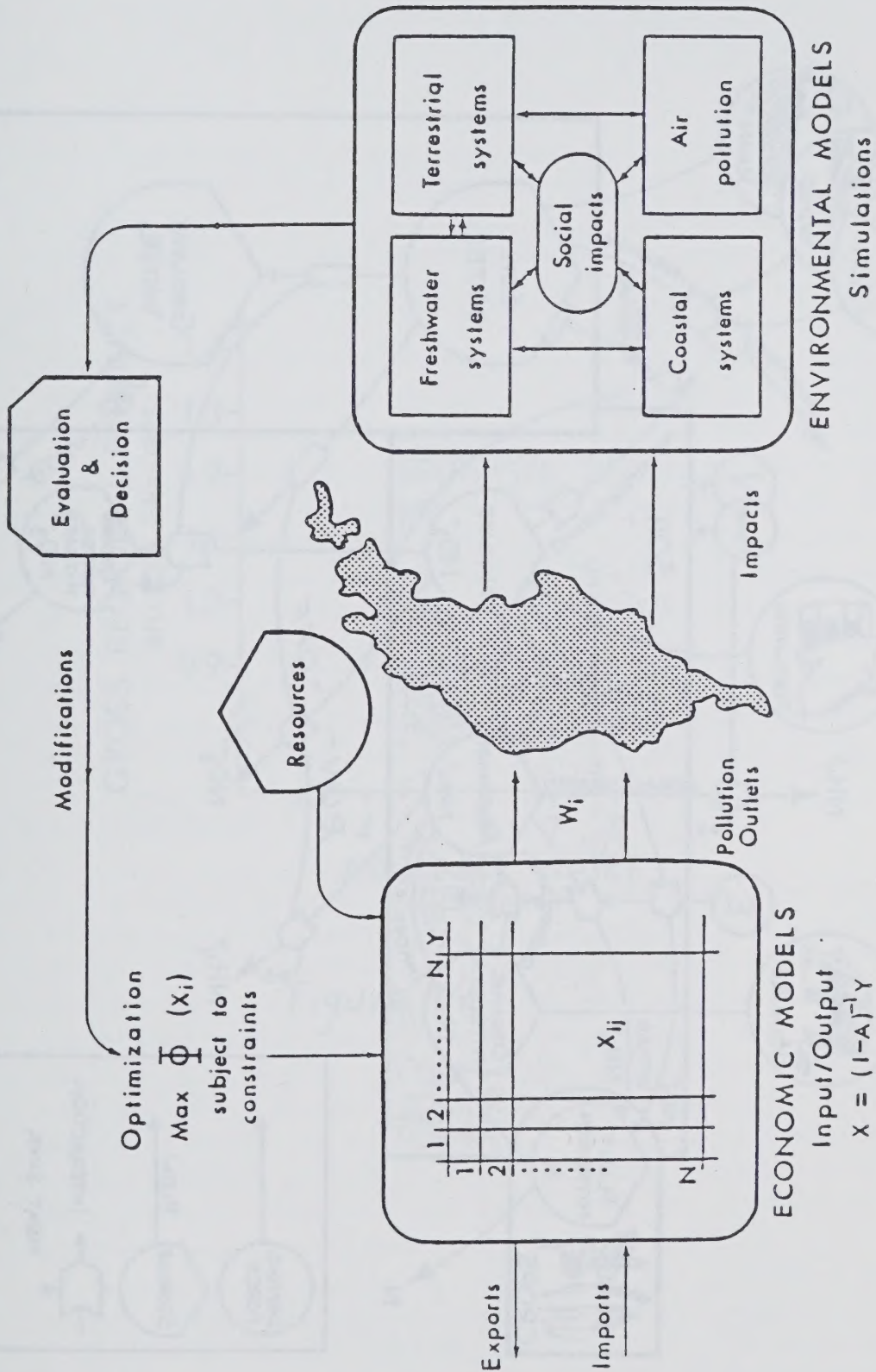


Figure 2

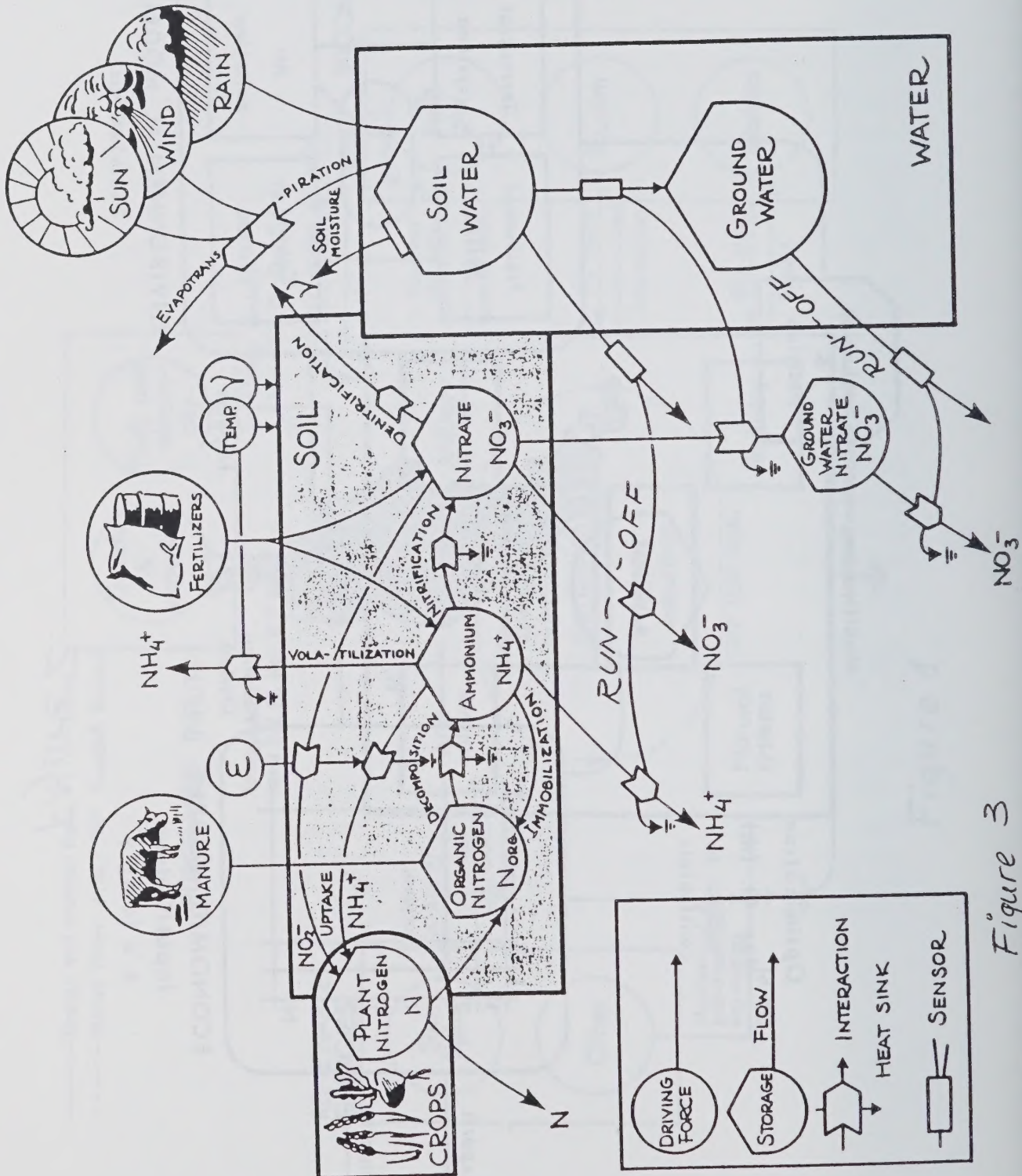


Figure 3

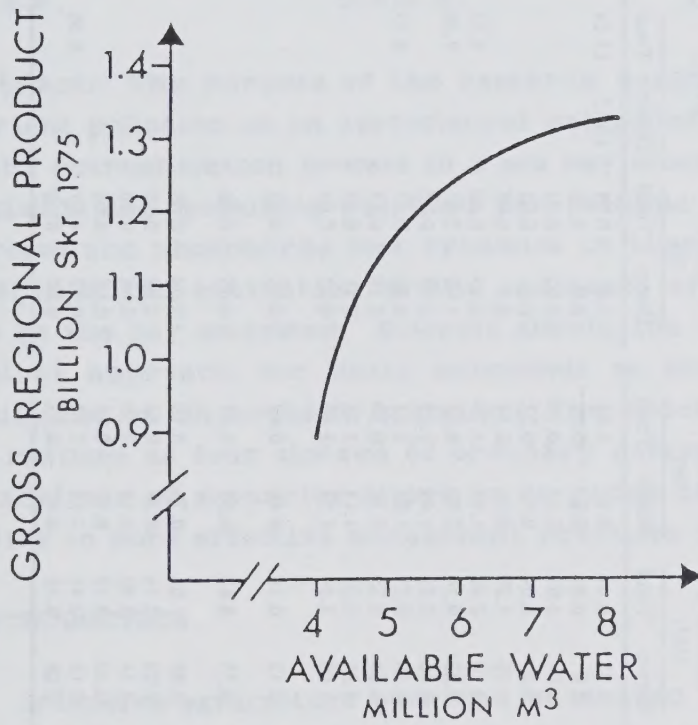


Figure 4

Table 1 Direct and Total Resource Requirements and Pollution Generation per Swedish Crown of Output, 1975

per Swedish Crown of Output, 1975																		
Sector	Employment /1000 Skr		Oil (MJ)		Electricity (MJ)		Water dm ³		BOD (g)		BOD _N ^a (g)		SO ₂ (g)		NO _x (g)		Value Added	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total
1.1	Animal	0.012	0.025	0.0	2.56	0.24	0.41	4.14	4.68	0.0	0.21	13.15	13.24	0.54	7.87	0.36	0.81	
	Crop	0.018	0.024	3.15	3.69	0.0	0.09	0.0	0.08	0.0	0.03			0.52	30.14	0.32	0.58	
1.2	Forestry	0.013	0.014	0.88	0.88	0.0	0.01	0.17	0.19	0.0	0.01			0.12	11.69	0.74	0.74	
2	Fishing	0.021	0.025	7.46	7.74	0.0	0.07	0.18	0.22	0.0	0.01			1.04	99.15	0.38	0.52	
3	Mining	0.006	0.009	1.61	6.04	1.10	1.20	0.06	0.14	0.3	0.05			0.38	0.10	3.52	0.91	
3.1.1	Slaughterery	0.004	0.021	0.23	2.41	0.10	0.40	1.47	4.78	0.45	0.60	9.37	9.37	0.06	0.01	5.60	0.82	
3.1.2	Dairy	0.004	0.022	1.64	4.34	0.22	0.54	2.90	6.23	1.90	2.05	9.40	9.40	0.39	0.07	5.71	0.83	
3.1.3	Sugar	0.005	0.018	5.50	8.94	0.46	0.53	1.45	1.51	0.08	0.10			1.29	17.24	0.40	0.71	
3.1	Other food	0.004	0.015	1.35	3.24	0.16	0.27	1.87	2.13	0.82	0.87	0.35	0.35	0.32	0.05	10.01	0.61	
3.2	Wood	0.015	0.021	0.47	2.43	0.24	0.35	0.24	0.39	0.10	0.11			0.11	0.54	3.78	0.87	
3.4.2	Printing	0.012	0.013	0.34	1.56	0.34	0.37	1.14	1.18	0.11	0.12			0.08	0.36	0.86	0.92	
3.6.9	Stone and soil	0.003	0.005	30.94	37.06	2.68	2.81	2.58	2.66	0.02	0.04			7.30	8.74	1.69	0.58	
3.8.3	Communication equipment	0.005	0.005	0.14	0.50	0.13	0.14	0.46	0.47	0.02	0.02			0.03	0.11	0.03	0.80	
	Other workshops	0.013	0.016	0.30	1.39	0.35	0.42	0.03	0.07	0.05	0.06			0.07	0.32	0.01	0.75	
4	Electricity and water	0.008	0.014	61.62	64.58	0.98	1.03	0.72	0.77	0.04	0.05			14.49	15.19	2.56	0.35	
5	Construction	0.014	0.015	0.0	0.81	0.09	0.14	0.27	0.33	0.09	0.10			0.17	1.48	0.76	0.83	
6.1/62	Wholesale	0.020	0.024	0.34	1.87	0.34	0.40	0.18	0.30	0.08	0.10			0.08	0.38	0.01	0.89	
7	Transports	0.010	0.015	2.80	3.74	0.10	0.15	0.10	0.21	0.05	0.08			0.24	29.79	34.73	0.71	
	Tourism	0.006	0.019	5.69	7.86	0.18	0.41	3.49	3.72	0.93	1.01	0.06	0.06	0.01	40.93	43.88	0.66	
8.9	Services	0.013	0.019	0.31	1.24	0.09	0.16	0.41	0.53	0.07	0.10			0.07	0.22	0.01	0.70	

^a BOD_N means output not connected to sewage treatment.

SIMULATION MODELLING AS A MEANS OF THE ASSESSMENT OF THE SEA BAY POLLUTION FROM NONPOINT SOURCES

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Abstract: The purpose of the research was to assess nonpoint nutrient pollution on an agricultural watershed and its influence on the eutrophication process in a sea bay ecosystem. The method of simulation modelling was used for reliable determination of nitrogen and phosphorus loss dynamics in time and space on the watershed and evaluation of the influence of excess nutrients flow on the bay ecosystem. Discrete simulation was chosen as the level of approach for basin submodels to provide point scale simulation of 501 areas of pollution. The model of the ecosystem was realized as four systems of ordinary differential equations. An analysis of scenarios allows us to range different measures leading to more effective management practices for the basin.

1. INTRODUCTION

Intensive agriculture over the watershed is often the main economic activity responsible for nutrients losses into the water. Agricultural pollution from point sources can be reduced through a number of economic measures. But the situation is more complicated in the case of nonpoint pollution sources represented by fertilized fields. The most important problem here is the reliable determination of nutrient loss dynamics in time and space. Because of its complexity, territorial spreading and non-uniqueness of solution, this problem requires the use of mathematical modelling for evaluating the effectiveness of different measures in reducing nutrients loading.

Nonpoint pollution is a source-transport problem in which the hydrological cycle provides the transport of pollutants from the source to a water body. Though there are a lot of different approaches to modelling, the basic principle is similar: at first

the hydrological model is constructed, and then the erosional and geochemical submodels are added. An approach similar to the one presented here has been used in the models of Williams [5], Haith and Tubbs [1], and also in the well-known CREAMS model [4,2].

The basin model described here includes HYDRO - a submodel of the water cycling on the watershed, and CHEM - a submodel of the nutrient migration on the watershed. For verification the model of nutrients transfer by the river flow was used [6]. To assess the effect of washed-off nutrients on a water body, a simulation model MATSALU was constructed simultaneously. Computer runs of the submodels HYDRO, CHEM and MATSALU were carried out on a computer IBM PC XT using RM/FORTRAN.

2. SITE DESCRIPTION

The object under consideration is the Matsalu Bay and its watershed. The Bay is located on the western coast of the Estonian SSR, in the Baltic Sea (Fig. 1). It is a part of the Vainameri (or the Moonsund) intruding deep into the land. Its area is 90 km², average depth 1.5 m. The Kasari River flows into the Bay from the east. It is about 113 km long with the watershed area of 3210 km². The average discharge of the river is 27 m³/sec. Heavy loams with low infiltration are widespread on the watershed, and about 80% of the annual runoff is formed as a result of snowmelt and rainwater flow. The average height above sea level is 20-50 m. The percentage of arable land on the watershed is about 25%. But intensive surface runoff carries along considerable amounts of nutrients, the bulk of which reaches the Matsalu Bay. Over two years special hydrochemical monitoring necessary for the calibration and verification of the model was carried out on three small sub-watersheds. In 1986 the annual average concentration of the mineral nitrogen in the Kasari River mouth was 2.1 mg/l, total phosphorus - 0.17 mg/l.

In the delta of the Kasari extensive flood plains and reedbeds have been formed. Of great importance here is the bird community, very diverse and rich both at nesting and migration time (reaching 1.5 mill. couples). The Bay together with the neighbouring land and sea forms the Matsalu State Reserve. About 1/4 of the Bay is covered with reeds *Phragmites australis*, and

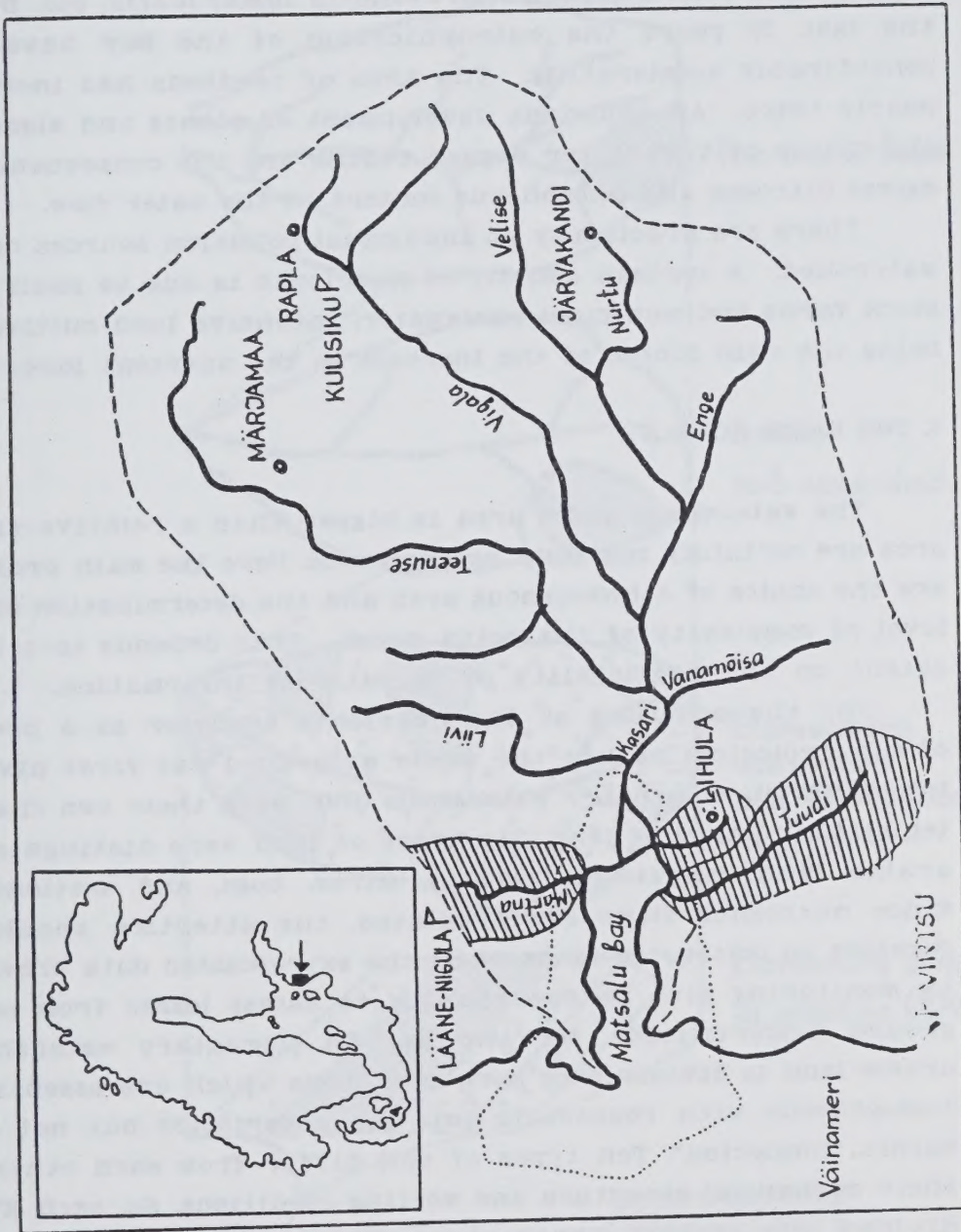


Fig.1 The Matsalu Bay and its watershed
- representative basins

the bottom of the remaining part is covered with submersed macrophytes *Chara aspera*, *Furcellaria lumbricalis*, etc. During the last 30 years the eutrophication of the Bay have been considerably accelerating. The area of reedbeds has increased nearly twice. An abundant development of plants and algae and the change of the winter oxygen regime are the consequences of excess nitrogen and phosphorus content in the water flow.

There are practically no industrial pollution sources on the watershed. A certain amount of nutrients is due to small live-stock farms and municipal wastewater, intensive land cultivation being the main source of the increase in the nutrient load.

3. THE BASIN MODELS

The watersheds whose area is bigger than a relative field's area are certainly spatially heterogenous. Here the main problems are the choice of a homogenous area and the determination of the level of complexity of the point model. This depends to a large extent on the availability of territorial information.

For the modelling of the nutrients transfer as a process of a hydrological nature the whole watershed was first divided into numerous elementary watersheds (EW) with their own characteristic structure of land. Six types of land were distinguished: arable land, hayfields, forests, mires, bogs, and settlements. Since nutrients flows are simulated, the attention should be focussed on cultivated lands while the extrapolated data provided by monitoring give an opportunity to assess losses from background (unfertilized) territories. An elementary watershed's arable land is divided once more into areas which are essentially homogeneous with respect to soil characteristics but not certainly "connected". Ten types of soil differ from each other by their mechanical structure and wetting conditions. So, each EW is divided into several elementary areas of pollution (EAP) which can be considered as homogeneous and can already be described by a point scale model. In our case out of the 1381 elementary areas of pollution 501 arable EAPs are to be simulated in the point scale. The average size of an EAP is 200 ha. While elementary watersheds covered the whole area of the basin, the formation of EAP leads to the construction of artificial spatial bodies and the desaggregation of the territory on that basis (Fig.2).

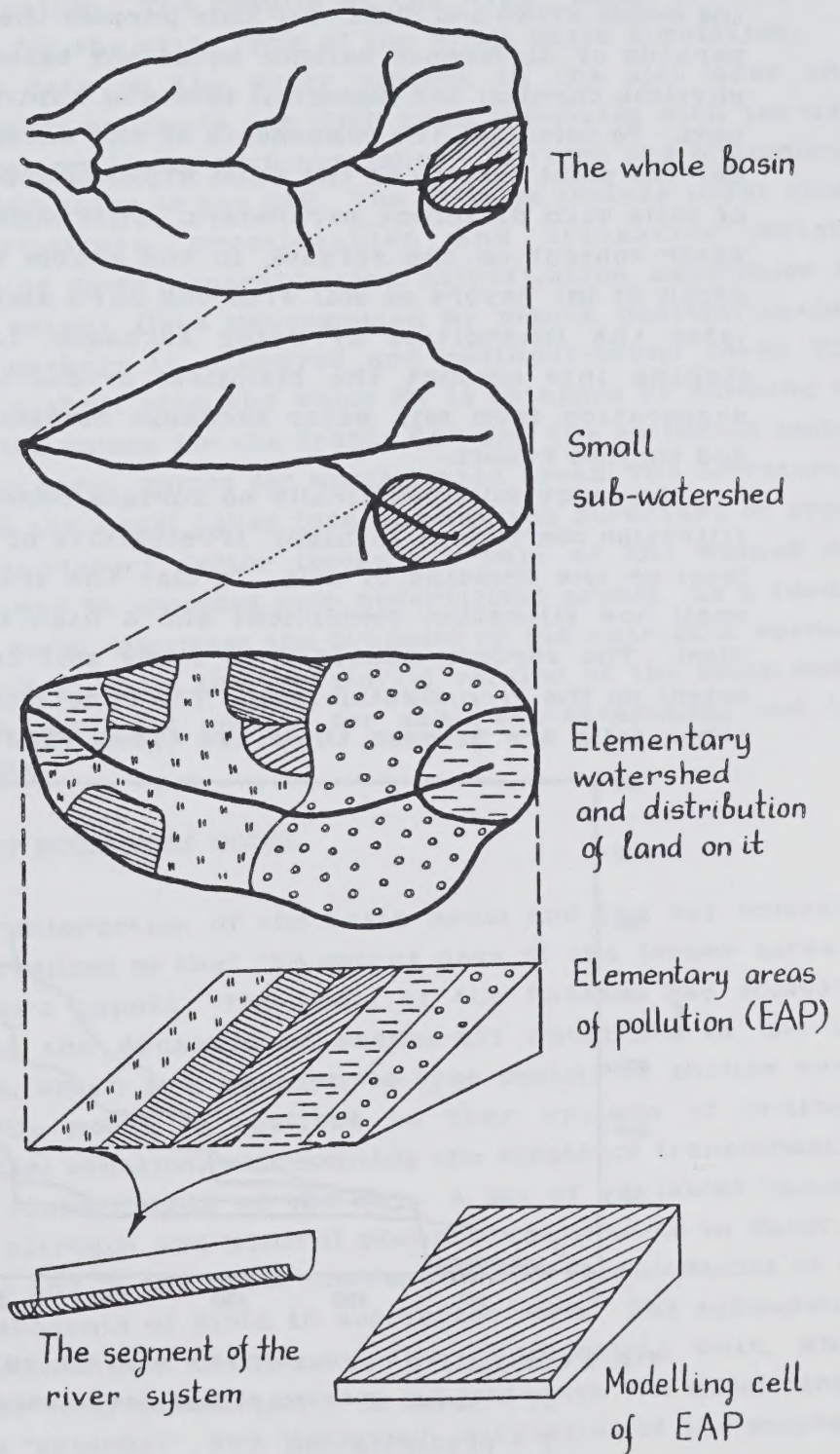


Fig.2 Desaggregation of the watershed

Discrete simulation was chosen as the level of approach for the models HYDRO and CHEM. For this purpose the mathematical apparatus of difference balance equations based on fundamental physical, chemical and biological laws and empirical material was used. To calculate the components of the water balance on each EAP the point version of the model HYDRO is applied for all types of soils with different parameters. This model determines the water content on the surface, in the arable and lower (to the depth of 1m) layers of soil with one day's step, and also calculates the intensities of water exchanges, i.e. transpiration (taking into account the biological production), infiltration, evaporation from soil, water exchange between the soil layers, and surface runoff.

On sandy soils practically no surface runoff is formed (the filtration coefficient is high) irrespective of the groundwater level or the freezing of soil. In clay the groundwater flow is small (low filtration coefficient and a high level of capillary rise). The surface runoff from loamy soil depend to a large extent on the groundwater level. The runoff characteristics of other soils are between these two types. Fig.3 shows that the

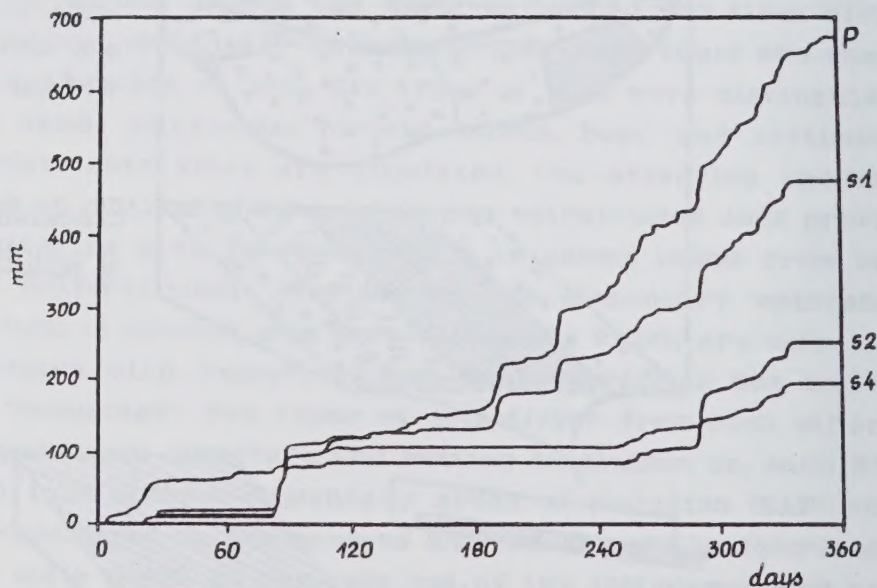


Fig. 3 Cumulative curves of the surface runoff for soils
s1 - loam, s2 - clay loam, s4 - sandy loam,
P - precipitation

heavier the soil, the closer its surface runoff curve to that of precipitation. The results of the HYDRO model provide the basic data for the water cycle of the whole basin simulation.

Using data on the water content in the soil layer and surface runoff as inputs, the CHEM model calculates with ten-day steps the balance of the main nutrients - nitrogen and phosphorus in the arable layer of the EAP. The balances include input flows (with fertilizers, precipitation and irrigation water), transforming flows (mineralization, nitrification, adsorption in soil), and output flows (consumption by plants, denitrification, leaching, washoff in dissolved and sediment-bound form). The nutrients washoff from the whole EW is obtained by summing up the computed values for the arable EAP and the estimated (using the samples data) values for uncultivated areas. The territorial version of the model takes into account the structure of crops and the transport factor (because a part of the washed off nutrients may be spreaded over unfertilized areas). As a result, the point model calculates the dynamics of the nutrients washoff from each EAP, while the territorial version of the basin model joins the calculated results for small sub-watersheds and the whole basin.

4. THE BAY ECOSYSTEM MODEL

The interaction of the basin model and the Bay ecosystem model is realized so that the output data of the former serve as the latter's inputs. The model of the Matsalu Bay ecosystem calculates the dynamics of washed-off nutrients in the Bay ecosystem, which is a macrophyte-type semiclosed shallow water body. The model is realized as four systems of ordinary differential equations representing the substance transformation in four compartments of the Bay. A set of variables includes mineral nitrogen and mineral phosphorus contents in water, in sediments and in the plant tissue, and also the biomasses of the main components of biota in aggregated form. The submodels of compartments are joined by the hydrological unit, which determines water exchange between compartments. The model permits to assess "external" and "internal" strategies of the ecosystem management.

5. VERIFICATION OF THE MODELS

Predicted nitrogen and phosphorus losses from the watershed should be compared with losses determined from water quality samples. After that model calculations of the formation of the nutrient load can be used for working out the best management practices. The sub-watershed of the Martna River (catchment area 187 km²) was chosen as the representative for the whole basin. The percentage of arable land on it is 21%. Application of mineral fertilizers amounts to 77 kg N/ha (1n spring) and 17 kg P/ha (1n autumn). Manure is applied in rotation annually to 13% of cultivated land (81 tons/ha) from autumn to spring. The main crops are cereals (barley) and perennial grass.

Fig.4 presents a comparison of the modelled dynamics of the nutrients wash-off from this watershed (nonpoint sources only) with the curves of the measured at the river outlet dynamics. With respect to quality the model corresponds well to the data of observation. Also, the annual wash-off of dissolved nutrients from the Martna watershed was determined as a result of modelling and calculated from the measured data (Tabl. 1). Loading from point sources was assessed by H.Kaljumae and others [3]. The comparison shows that the model gives quite satisfactory results. The total modelled loading differs from the calculated one by 4-6%, the annual dynamics of losses is similar to the observed, too. Subsequent verification on the whole watershed gave similar results.

Table 1

Washoff of dissolved nitrogen and phosphorus from the watershed of the Martna River, 1986y.

Loading	Nitrogen		Phosphorus	
	t N/a	%	t P/a	%
Measured	119.5	100	4.35	100
Calculated, including	111.8	93.6	4.52	103.8
- wash-off from fields	56.5		3.03	
- leaching from fields	16.6		0.25	
- uncultivated areas	23.9		0.31	
- point sources	14.8		0.93	

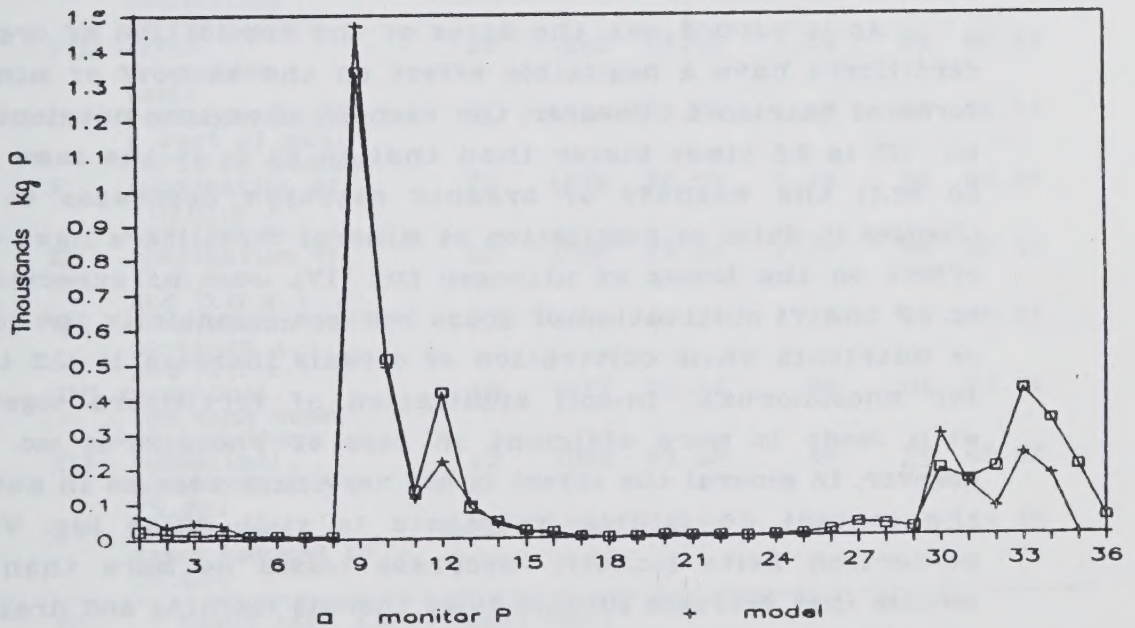
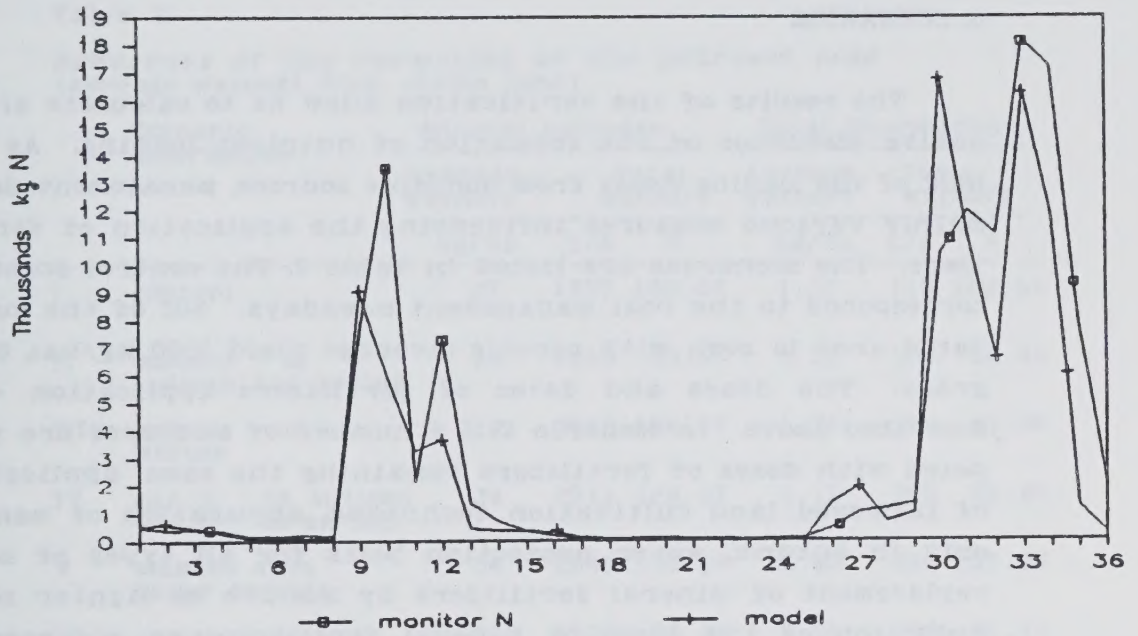


Fig. 4 Dynamics of the nutrients washoff from the Martna watershed

6. SCENARIOS

The results of the verification allow us to calculate alternative scenarios of the formation of nutrient loading. As the bulk of the loading comes from nonpoint sources, management means mainly various measures influencing the application of fertilizers. The scenarios are listed in Table 2. The control scenario corresponds to the real management nowadays. 40% of the cultivated area is sown with cereals (average yield 3000 kg/ha), 60% - grass. The doses and dates of fertilizers application - as described above. In scenario XIII a number of measures are proposed with doses of fertilizers remaining the same: application of improved land cultivation technique, application of manure only in autumn, water protection belts for all types of soils, replacement of mineral fertilizers by manure on lighter soils, reduction of the doses of mineral fertilizers on organogenic soil. In scenarios XIV and XV the reduction of the doses of mineral fertilizers was analysed.

As it turned out, the dates of the application of organic fertilizers have a negligible effect on the washoff of mineral forms of nutrients. However, the washoff of organic nutrients in sc. III is 2.2 times bigger than that in sc. I. At the same time in sc. II the washoff of organic nitrogen decreases to 37%. Changes in dates of application of mineral fertilizers have more effect on the losses of nitrogen (sc. IV). Just as expected, in sc. V and VI cultivation of grass reduces essentially the losses of nutrients while cultivation of cereals increase it (2.5 times for phosphorus!). In-soil application of fertilizers together with seeds is more efficient in case of phosphorus (sc. VII). However, in general the effect is not very high because in autumn the content of soluble nutrients is still quite big. Water protection belts (sc. VIII) decrease losses no more than 10%, because they decrease surface flows whereas leaching and drainage flows form the bulk of washoff on lighter soils. The replacement of a part of mineral fertilizers by manure is more effective in the case of nitrogen (sc. IX). Scenarios X-XIII are different combinations of previous ones. In suboptimal scenario XIII the nutrients loading is 24-26% smaller. When in addition the doses of fertilizers are reduced, the percentages of reduction are

Table 2

Scenarios of the formation of the nutrient load
(average washoff from arable land)

	Scenario description	Mineral nitrogen			Total phosphorus		
		Average washoff	Total washoff		Average washoff	Total washoff	
		kg/ha	t/a	%	kg/ha	t/a	%
I	control	27	1957	100.0%	1.37	110	100.0%
II	manure - in autumn and spring	26	1866	95.4%	1.33	106	96.4%
III	manure - in winter	29	2048	104.6%	1.36	109	99.0%
IV	min.N - in autumn min.P - in spring	36	2511	128.3%	1.17	105	95.2%
V	planted area under cereals	34	2548	130.2%	3.60	284	257.0%
VI	planted area under grass	21	1590	81.2%	1.28	100	91.1%
VII	in-soil application of fertilizers	26	1843	94.2%	.98	84	76.6%
VIII	water protection belts	26	1828	93.4%	1.29	99	89.5%
IX	replacement of a part of min. fert. by manure	21	1481	75.7%	1.23	100	90.7%
X	combination of VIII(h.s.) and IX(l.s.)	23	1672	85.5%	1.14	92	83.6%
XI	combination of VI(h.s.) and IX(l.s.)	22	1555	79.5%	1.17	96	87.1%
XII	combination of no-till(h.s.) and IX(l.s.)	23	1685	86.1%	1.16	95	86.2%
XIII	suboptimal, the same doses of fertilizers	18	1477	75.5%	.94	81	73.9%
XIV	suboptimal, doses reduced to 75.00%	13	1088	55.6%	.90	74	66.9%
XV	suboptimal, doses reduced to 50.00%	8.50	706	36.1%	.90	71	64.4%

(h.s. - heavy soil, l.s. - light soil)

more essential. Thus, reduction of loading requires taking rather drastic measures, including decrease in the doses of fertilizers.

The calculation of scenarios with the MATSALU model have been carried out as well. 50% decrease in nutrients loading proved to result in a substantial reduction in the phytoplankton biomass, but it had no effect on emergent plants. On the other hand, the summer cutting of the aboveground parts of reeds decreased their productivity in the next vegetation season. This reflects the fact that in the littoral zone of an eutrophic water body emergent plants have a sufficient supply of nutrients in their roots and sediments to support the existing level of productivity under unfavourable conditions in one year only after decades of surplus loading.

As the eutrophication process in the Bay is revealed first of all by the extension of the reed-covered area, the improvement of the situation is possible only by means of a number of measures both on the watershed area and in the bay. As a whole, the obtained results demonstrate the applicability and good prospects of a simulation technique for solving problems of environmental protection.

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ON THE USE OF HIERARCHICAL OPTIMIZATION IN AQUATIC ECOSYSTEM

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In the paper hierarchical approach to the problem of ecological water systems control is presented. The model describes interactions between components of aquatic ecosystem (phytoplankton and zooplankton) and wastewater conditioning these components evolution. The model concerns lakes only. It is assumed, that a growth of plant and animal organisms in lakes depends on the pollutant quality coefficient such as various forms of phosphorus, nitrogen and dissolved oxygen.

The model consists of a number of submodels describing variations of some selected quality coefficients as well as variations in phytoplankton and zooplankton populations.

The following processes are considered: growth and mortality of organisms, assimilation of nonorganic nutrients in growth processes and organic nutrients sedimentation. Phytoplankton and zooplankton changes are described by the system of ordinary differential equations with growth and respiration coefficients as parameters. The coefficients are considered to be functions of phosphorus and nitrogen concentration. Submodels of concentration changes of water quality indices reflect both physical and biochemical processes in water.

The model objective is to determine such a strategy for waste loads discharges which guarantees ecological equilibrium in the lake. Because there are interconnections between particular sub-models it is quite natural to apply hierarchical structure control for the global model under consideration.

1. The basic assumptions of ecological models

The ecological models of lake compose of two interacting components: a submodel describing biochemical processes and that describing water transportation of water.

The biochemical submodel reflects variations in phyto and zooplankton populations and in the concentration of such substances as phosphorus, nitrogen etc.. The biochemical processes are related to the growth and mortality of organisms, nonorganic nutrients assimilation and sedimentation.

The water transportation submodel reflects the structure of the spatial partition of lake. This structure has the form of the sequence of layers (segments), homogeneous from the point of view of pollutant concentration.

For the layer-division it is necessary to determine the morphometric parameter of each segment and the mixed and diffusion coefficients.

This division can be illustrated as in Fig. 1.

The mass conservation equation for a discrete thickness Δz is of the form :

$$\frac{\partial V_j}{\partial t} = Q_j - Q_{j+1} - Q_{ij} + Q_{0j} \quad (1)$$

where :

V_j - volume of the j -th element,

Q_j - vertical flow rate,

Q_{ij} - flow advected to the control volume in the horizontal plane,

Q_{0j} - flow advected from the control volume in the horizontal plane,

and all flows are functions of time.

Based on this relation the general mass conservation equation for the j -th element of a lake layer is:

$$\frac{\partial (V_j C_j)}{\partial t} = \underbrace{-Q_j C_j + Q_{j+1} C_{j+1}}_{\text{advection}} + \underbrace{(E_a \frac{\partial C}{\partial Z})_j - (E_a \frac{\partial C}{\partial Z})_{j+1}}_{\text{diffusion}}$$

$$+ \underbrace{C_j \frac{\partial V_j}{\partial t}}_{\text{volume change}} + \underbrace{V_j \frac{\partial C}{\partial t}}_{\text{local derivative}} \quad (2)$$

volume change local derivative

where :

C_j - is the concentration of any quality constituent in the fluid mass,

$\frac{\partial C}{\partial t}$ - local derivative represents all processes other than advection and diffusion that act to change the concentration in the volume V_j .

In ecological model under consideration we assume that the body of water is ideally mixed, i.e. the concentration of a substance in the body can be considered to be completely homogeneous - diffusion can be neglected.

These assumptions can concern either one of the layer of a lake or lakes in which the extent of turbulence due to wind, tides or other forces is so great that for practical purposes the concentration is homogenous. In the second case we assume that a lake is a nonstratified, well mixed reservoir, in which concentration changes of constituents being considered depend only on time.

It is assumed that the growth of plants and organisms in lake depends on the pollutant quality coefficients such as phosphorus and nitrogen. In the model the following processes are considered: zooplankton grazing, respiration, nutrients sedimentation and biodegradation.

2. The hierarchical structure of ecological model of lake

Under above assumptions the model describing variation of nitrogen and phosphorus concentration as well as variations in phytoplankton and zooplankton populations has the form of following differential equations :

$$\frac{d A}{d t} = (\mu_a - r_a - s_a - m_a) A - \frac{\mu_z Z}{d} - \frac{Q \cdot A}{V} \quad (3)$$

$$\frac{d Z}{d t} = (\mu_z - r_z - m_z) Z - \frac{\mu_f F}{d} - \frac{Q \cdot Z}{V} \quad (4)$$

$$\begin{aligned} \frac{d P}{d t} = & \frac{Q_d P_d}{V} + Z_p + \alpha_s P - \frac{(\mu_a - r_a) A}{\alpha_p} + \frac{r_z \cdot Z}{\alpha_p} - \frac{Q \cdot P}{V} + \\ & + k_4 dp k_6 \end{aligned} \quad (5)$$

$$\frac{dN}{dt} = \frac{Q_d \cdot N_d}{V} + Z_n + \beta_s N - \frac{k_d N}{V} - \frac{(\mu_a - r_a)A}{\beta_p} + \frac{r_z \cdot Z}{\beta_p} +$$

$$+ k_4 dn k_b - \frac{Q \cdot N}{V} \quad (6)$$

where:

A - phytoplankton concentration

Z - zooplankton concentration

P - phosphorus dissolved in lake water

N - nitrogen dissolved in lake water

Q - rate of total outflow from the lake

V - volume of the lake

F - fish concentration

Q_d - rate of total inflow to the lake

The parameters are :

m_a - mortality of phytoplankton

m_z - mortality of zooplankton

r_a - respiration rate of phytoplankton

r_z - respiration rate of zooplankton

(r_a and r_z depend on the temperature)

s_a - settling rate

d - conversion factor phytoplankton - zooplankton biomass

α_p - phosphorus content in plankton

β_p - nitrogen content in plankton

α_s - parameter associated with sedimentation of phosphorus

β_s - parameter associated with sedimentation of nitrogen

k_4 - biodegradation coefficient of detritus

dn - detritus nitrogen in lake water

k_b - temperature coefficient for biodegradation

k_d - a constant describing denitrification rate

P_d - phosphorus in streams going to the lake

N_d - nitrogen in streams going to the lake

The coefficient μ_a is the growth rate of phytoplankton and it depends on the nitrogen and phosphorus concentration, on temperature and light.

The nonlinear relationship between nitrogen and phosphorus concentrations and the coefficient μ_a takes the form:

$$\mu_a = \mu_{amax}(T, L) \frac{N}{k_n + N} \cdot \frac{P}{k_p + P} \quad (7)$$

where :

k_n - a constant describing nitrogen uptake

k_p - a constant describing phosphorus uptake.

The coefficient μ_z is growth rate of zooplankton and it depends on temperature and photoplankton concentration. This nonlinear function reflecting this dependence is given by:

$$\mu_z = \mu_{zmax}(T, L) \frac{A}{k_a + A} \quad (8)$$

where :

k_a - a constant describing feeding rate of zooplankton

The coefficient μ_f describing the growth rate of fish population is of the following form :

$$\mu_f = \mu_{fmax}(T) \frac{Z}{k_z + Z} \quad (9)$$

where: k_z - a constant for feeding rate of fish

Z_p, Z_n - waste load discharged to the lake.

As results from the system (3) - (6), the model describing aquatic ecosystem is of nonlinear form and can be decomposed into three submodels :

- a) a submodel describing variations in phytoplankton population,
- b) a submodel describing variations in zooplankton population,
- c) a submodel describing variations of nitrogen and phosphorus concentrations.

The submodels are interconnected as shown in Fig.2.

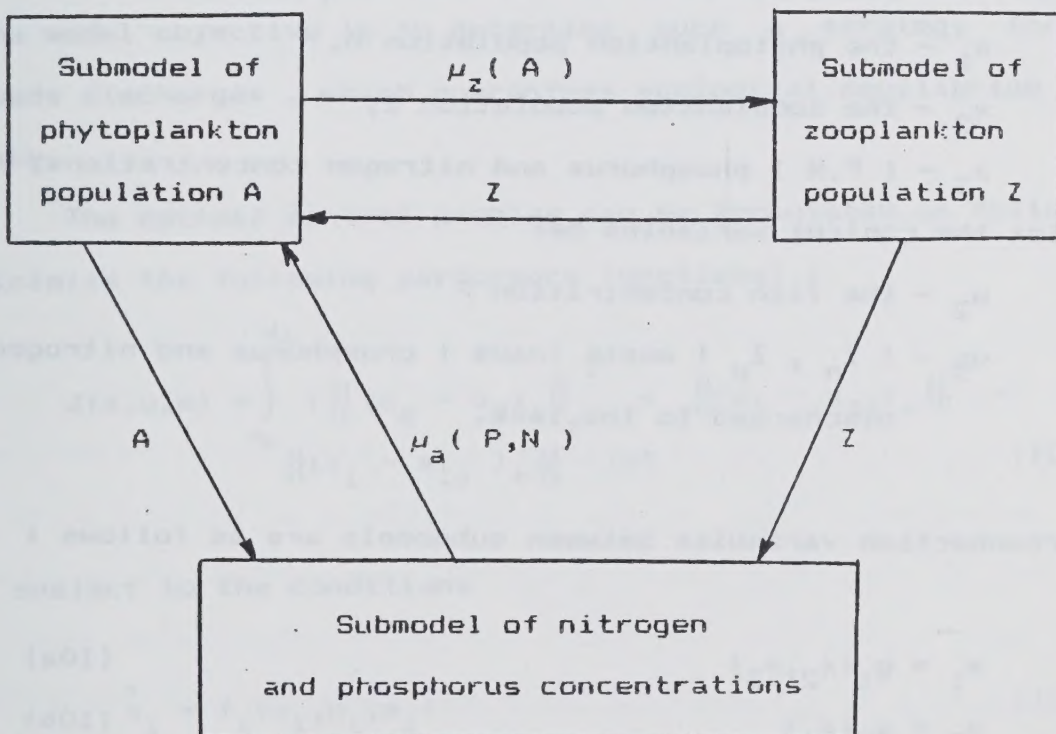


Fig.2 Interconnection between submodels in aquatic ecosystem

The global model composed of these submodels is given by the system of ordinary nonlinear differential equations (3) - (6).

3. The formulation of hierarchical control problem

As follows from the equations (3) - (6) the interconnection between submodels is realized ,among others, by the growth coefficients μ_a , μ_z , where the coefficient μ_a is a function of nitrogen and phosphorus concentrations and μ_z is a function of the phytoplankton population. Each submodel is described by the appropriate equation, i.e. the submodel of phytoplankton population is given by the equation (3), the submodel of zooplankton population is given by the equation (4) whereas equations (5) - (6) describe the submodel of nitrogen and phosphorus concentrations.

Let the state variable for the subsequent submodels be:

x_1 - the phytoplankton population A,

x_2 - the zooplankton population Z,

x_3 - (P,N) phosphorus and nitrogen concentrations,

and let the control variables be:

u_2 - the fish concentration F

u_3 - (Z_n , Z_p) waste loads (phosphorus and nitrogen) discharged to the lake.

Interconnection variables between submodels are as follows :

$$m_1 = g_1(x_2, x_3) \quad (10a)$$

$$m_2 = g_2(x_1) \quad (10b)$$

$$m_3 = g_3(x_1, x_2) \quad (10c)$$

The functions $g_i()$, $i = 1, \dots, 3$ are nonlinear functions of phytoplankton and zooplankton populations and of phosphorus and nitrogen concentrations.

Assuming this notation we can express the system (3)-(6) in the following form :

- the system of state equations for each submodel

$$\dot{x}_i = f_i(x_i, u_i, m_i) \quad i = 1, 2, 3 \quad (11a)$$

where: $f_i(.,.,.)$ is a nonlinear function,

- the system of interconnection equations

$$m_i = g_i(x_j) \quad j \neq i \quad i = 1, 2, 3 \quad (11b)$$

The model objective is to determine such a strategy for waste loads discharges, which guarantees ecological equilibrium in the lake.

The optimal control problem can be formulated as follows :

Minimize the following performance functional :

$$J(x, u, m) = \int_{t_0}^{t_1} (\| (u_d - u_2)_+ \|_2^2 + \| (x_3 - x_{3d})_+ \|^2 + \| (x_1 - x_{1d})_+ \|^2) dt \quad (12a)$$

subject to the conditions

$$\dot{x}_i = f_i(x_i, u_i, m_i) \quad (12b)$$

$$g_i = L_{ij} g_j(x_j) \quad (12c)$$

where :

u_d - is a desirable fish concentration,

x_{3d} - is a desirable quality level,

x_{1d} - corresponds to drinking-water quality requirements.

To solve this problem we apply the two-level coordination method based on the augmented Lagrange functional associated with inter-connection equations.

This leads to a two-level problem structure :

The first-level problem consists in independent minimization of the local functional with respect to state and control variables. For given multipliers π and interaction variables m we obtain the following first-level optimization problem :

Minimize the local augmented functional :

$$L_i(x_i, u_i, m, \pi) = J_i(x_i, u_i) + \langle \pi_i, m_i \rangle + 0.5\rho \|m_i\|^2 + \\ + 0.5\rho \|g_i(x_i)\|^2 - \rho \left\langle \sum_{j=1}^3 m_j, g_i(x_i) \right\rangle - \left\langle \sum_j \pi_j, g_i(x_i) \right\rangle \quad (13)$$

subject to the state equation :

$$\dot{x}_i = f_i(x_i, u_i, m_i) \quad i = 1, \dots, 3$$

where :

$$J(x, u) = \sum_{i=1}^3 J_i(x_i, u_i) \\ J_1(\) = \int_{t_0}^{t_1} \| (x_1 - x_{1d})_+ \|^2 dt \\ J_2(\) = \int_{t_0}^{t_1} \| (u_d - u_2)_+ \|^2 dt \\ J_3(\) = \int_{t_0}^{t_1} \| (x_3 - x_{3d})_+ \|^2 dt$$

The first-level optimization gives optimal values of variables x_i , u_i for each subsystem (submodel).

The values of multipliers π and interconnection variables m are fixed by the second level.

The task of the second level consists in determining such values of multipliers π and interaction variables m , which guarantee global optimum for the whole system. The Lagrange multi-

pliers are associated with the interconnection equations.

The second-level problem is of following form :

Maximize the dual functional $L_d(\pi, m)$ with respect to multipliers π and variables m ,

where:

$$L_d(\pi, m) = L_{di}(\pi, m)$$

$$L_{di}(\pi, m) = \min L_i(x_i, u_i, \pi, m)$$

$$(x_i, u_i) \in D_i$$

The set D_i is a set of variables x_i, u_i , which satisfy the state equation .

4. Conclusion

The model presented in the paper deals with the problem of waste load discharge optimal control. Well mixed reservoir is considered. Multilevel method of problem solving is applied. If a lake is treated as a sequence of layers with homogeneous pollutants concentration then the hierarchical structure of the problem is more complicated. It is the result of interconnections between particular layers. Each lake layer is modelled as a system of interconnected submodels and the water quality control problem is solved with the aid of the two-level optimization method.

The model of the whole lake should consist of the ecosystem models obtained for particular lake layers and should reflect both advection and diffusion processes.

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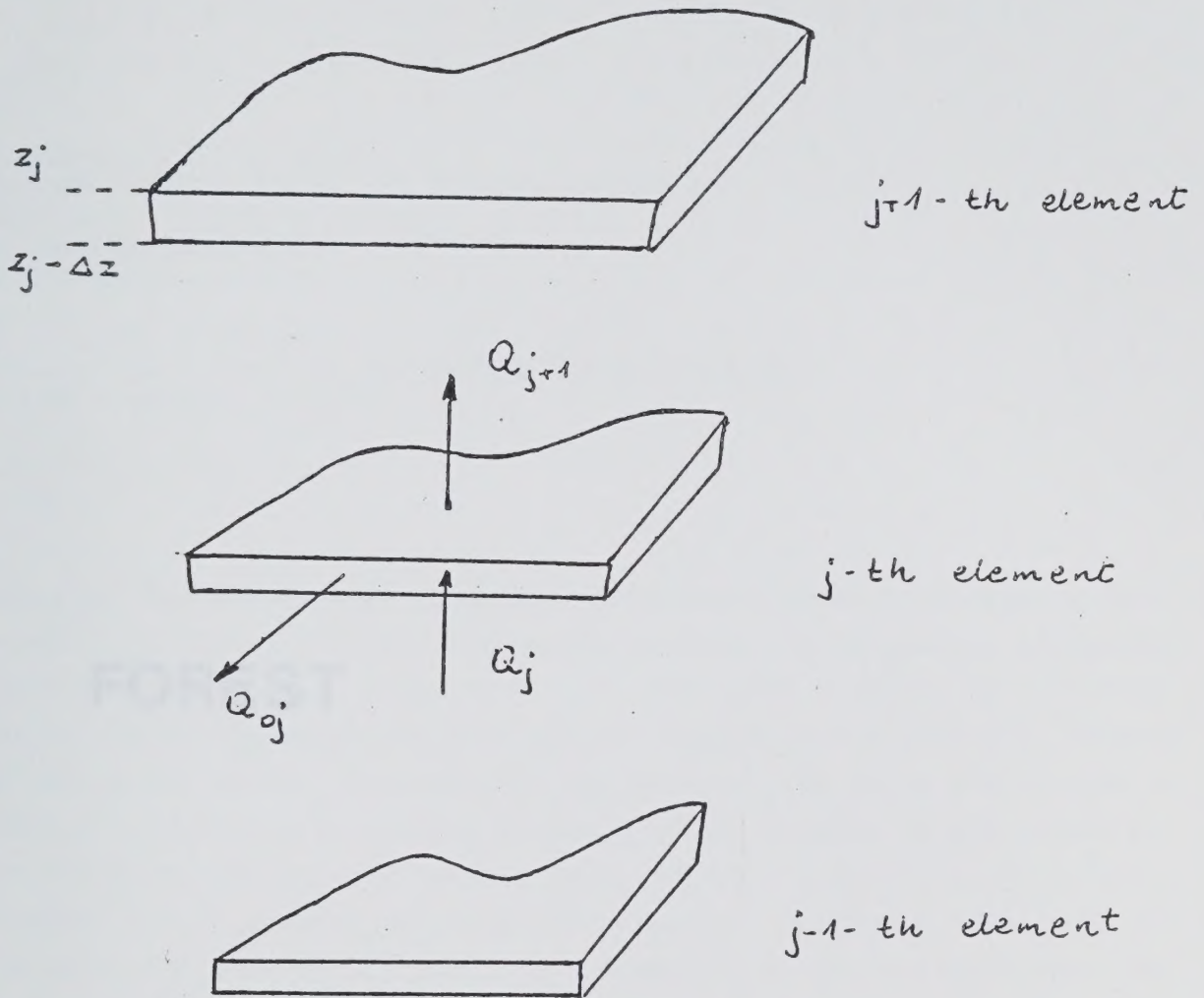


Fig.1 The layer-division of lake

where :

z_j - depth of layer

Q_j - vertical inflow to the j -th segment

Q_{j+1} - vertical outflow from the j -th segment, which is
the inflow to the $j+1$ -th segment

Q_{0j} - horizontal flow

INSTITUTIONAL RESEARCH
AND THE FOREST

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FOREST

The present paper gives a description of preliminary studies done in the field of forestry by the Department of Forestry, University of Wisconsin at Stevens Point, and the International Institute for Tropical Agriculture, Ibadan, Nigeria. The main objectives of the study are to find a way to improve the management of the forest resources of the country, and to find a way to improve the management of the forest resources of the country. The study is done in the field of forestry, and the results of the study are presented in the form of a report. The study is done in the field of forestry, and the results of the study are presented in the form of a report. The study is done in the field of forestry, and the results of the study are presented in the form of a report.

1. INTRODUCTION

In recent years, the study of the forest resources of the country has become a subject of increasing interest. The study of the forest resources of the country has become a subject of increasing interest. The study of the forest resources of the country has become a subject of increasing interest. The study of the forest resources of the country has become a subject of increasing interest. The study of the forest resources of the country has become a subject of increasing interest.

According to the latest of official statistics, the forest resources of the country are estimated to be 100 million acres. The forest resources of the country are estimated to be 100 million acres. The forest resources of the country are estimated to be 100 million acres. The forest resources of the country are estimated to be 100 million acres. The forest resources of the country are estimated to be 100 million acres.

FOREST

IMPLICATIONS OF FOREST DECLINE FOR THE POLISH FOREST SECTOR

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Abstract The present paper gives a description of preliminary results from a study carried out by the Department of Forestry Engineering of Warsaw Agricultural Academy in cooperation with the Forest Study of the Biosphere Project at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. The overall objectives of the study are to take a national perspective in building scenarios of the possible future courses of the Polish forests and wood industry under different assumptions about forest decline, and to examine the range of management strategies that could be implemented to cope with the problems continued forest decline might pose. The study consists of a number of strongly linked components including among the other: simulation and optimization models, as well as a "policy exercise" - an approach developed at IIASA for bringing scientists and policy-makers together for intensive interaction and mutual learning about shared problems.

1. INTRODUCTION

In recent years, the state of the forest environment in Poland has brought justified worry. The total area of stands under the different stress factors leading to forest decline as well as a number of these factors increase every year. There are already some forest areas where, decline has reached the extent of ecological catastrophe (e.g. Sudety Mountains), see Mazurski, 1986.

According to the latest of official estimates, visible symptoms of damage occur on 8% of total forest area in Poland. It is estimated that hidden physiological damage can be found on 50% of total forest area. The increment

losses alone were assessed to be about 3 million m³ annually, a volume having a value of approximately 25 milliard zlotys.

For the last few years many studies on the forest decline phenomena and its consequences have been undertaken. The Department of Forestry Engineering of Warsaw Agricultural Academy in cooperation with Forest Study of the Biosphere Project at IIASA and with the help of the research teams from Wood Technology Institute in Poznan and Agricultural Academy of Krakow is conducting a study on the impacts of forest decline on future wood supply and utilization of wood in Poland over the next few decades.

The overall goals of the study are to take a national perspective in building scenarios of possible future of the Polish forests and forest products industry under alternative assumptions about continued forest decline, and to examine the range of management strategies that could be implemented to cope with the problems continued forest decline might pose.

The study is composed of a number of strongly linked components (figure 1) including: (a) a wood-supply modelling effort, using a custom-built, updated forest-resources and forest-decline database for Poland and a wood-supply model built by scientists from IIASA and adapted to the Polish forests; (b) an examination of new silviculture regimes appropriate for managing declining forest stands; (c) an investigation into the changes in wood quality due to air pollution; (d) a study of the structural changes that may be required in the Polish forest-products industry in view of a changing quality and quantity of wood supply; (e) optimization-modelling work looking at the implications of changing wood supply on mechanization of harvesting and silviculture, and (f) a detailed examination of the management strategies that the forest sector policy-makers could pursue to improve the condition of Polish forests at the same time as maintaining a healthy wood-products industry and meeting the domestic demand for wood products as much as possible. The management component of the study will center around a workshop (Warsaw, November 1988) based on "policy exercise", an approach developed at IIASA for bringing scientists and policy-makers together for intensive interaction and mutual learning about shared problems. It is expected that the workshop participants will identify both the constraints against and

opportunities for improved management of the Polish forest and wood industry over the next few decades. The structure of the whole study has been shown in fig. 1.

2. FOREST RESOURCES AND FOREST DECLINE DUE TO AIR POLLUTION

Poland is characterized by comparatively low afforestation rate which is currently equal to 27.6%. The share of forest area per inhabitant is only 0.23 ha [1]. The total forest area, the total volume, the mean volume per hectare are respectively: 8,666,545 ha, 1,324 mln m^3 and 152.8 m^3 /ha [2]. The ownership structure is as follows: state forests - 82.3%, while non-state forests - 17.7% of the total forest area in the country. A decisive role in managing of Polish forests is played by the State Forests Enterprises (78.5% of the total forest area, 85.9% of the total volume and 92% of the total yearly wood harvest in the country). Within the forests that belong to the State Forests Enterprises the mean volume per hectare, current growth, mean harvest per hectare are respectively: 178 m^3 /ha, 6 m^3 /ha/year and 3.30 m^3 /ha/year. If we take private forest for a comparison, the given parameters are equal to: 101 m^3 /ha, 4 m^3 /ha/year and 0.89 m^3 /ha/year.

Unfavorable production conditions of Polish forests and their low natural resistance against damage-causing agents result from:

- 1) unfavorable site pattern (nutrient-poor dry wood sites - 69.6%, mountainous sites - 8.7%, while forest sites - only 21.7% of total forest area);
- 2) inadequate species composition of stands (which was altered because of forest-management activities aimed at introducing coniferous species for economic reasons - now coniferous stands occupy 79.7% (pine 70.5%, spruce 6.5%) of total forest area;
- 3) artificial regeneration of stands in disregard of site conditions;
- 4) unfavorable age structure of forests (e.g. within forests belonging to the State Forests Enterprises stands of age up to 40 comprise 41.5% of all forest area, from 41 to 80 years 39.3%, and older than 80 years only 19.2% - the age structure of other forests is even worse);

- 5) in most cases of regeneration of stands at the end of last century seeds of foreign origin were used;
- 6) managing the forests by way of clear cutting as the only method (this led to development of even-aged stands).

The research team from Agricultural Academy of Krakow under the guidance of Prof. J. Greszta has estimated current extent and range of forest damages due to air pollution and elaborated the map of threat damage zones for the whole country. On the basis of the obtained results it was estimated that 33% of Polish forests (i.e. 2,853,741 ha) were affected by industrial emissions. 62% of this area (i.e. 1,769,314 ha) are located in zone I with the smallest degree of damage, 30% (856,120 ha) in zone II with medium damages, and 8% (228,399 ha) in zone III with the greatest damages [3].

The obtained results differ from the data given by the National Board of the State Forests Enterprises. The latter claim that only 7.8% of all forest land (i.e. 645,927 ha) is damaged (zones I, II and III altogether). It is regarded that these data minimize the range of forest damages.

The absolute extent of zone areas is still not as alarming as their dynamic increase. Fig. 2 shows the dynamic of threat zone's areas increase as well as the dynamic of increase of the total forest area damaged by air pollutants.

3. PROGNOSIS OF FUTURE WOOD SUPPLY UP TO 2020

In the present studies two variants of potential wood supply in Poland up to the year 2020 have been elaborated. This was done on the basis of preliminary results of prognostic investigations of the research team from Forest Research Institute in Warsaw under the guidance of Prof. T. Trampl (after [4]). Variant I is optimistic and Variant II is pessimistic. Each is identical in total volume harvested, but differs in wood commodity structure. Variant I - optimistic was calculated under the assumption of theoretical growth of forest stands - effects of air pollution have not been taken into account. Variant II - pessimistic have been calculated using reduced growth coefficients due to air pollution. The reduced growth coefficients were assessed regarding biogeographical region, threat zone, species, etc.

Potential wood harvest for each variant was derived basing on current and foreseen age structure of Polish forests and making assumption that harvest in a stand of a given species cannot exceed it's actual growth.

In pessimistic variant (II) there was an assumption that damage-causing agents having long term effects on forests, such as air pollution, decrease their natural resistance and make them more vulnerable to diseases. This should result in forced exceeded sanitary operations, diminished final cuttings, shortened rotation period, exceeded production of thin wood and decreased of thick wood, reductions in wood quality, increased production of hardwood in relation to the total removals. In the diagram (Fig. 3) two: optimistic and pessimistic prognosis of wood commodities supply has been presented [4].

4. IMPACT OF AIR POLLUTION ON WOOD QUALITY

In order to determine quality of wood from trees in damaged forests experimental investigations of anatomical, physical and chemical properties of pine wood from 60 years old stands located in different threat zones (I to III) have been undertaken (see Splawa-Neyman et al). Wood from stands located in zone "0" - i.e. with no damage, have been used as control wood.

In the result of above mentioned investigations it was revealed that wood from damaged forests in regard to control wood [5]:

- 1) has higher joint thickness of two cell walls, especially in late wood;
- 2) is characterized by lowered mechanical properties;
- 3) has higher contents of solubles and extractives and distinctly lower alpha-cellulose contents, and
- 4) possesses a little lower equilibrium moisture contents and higher wood pH.

On the basis of the obtained results economic losses of wood quality changes can be estimated. These losses will include among the others:

- 1) losses due to a decrease of diameters of saw logs (e.g. 5.7 cm - for 60-year-old stands);
- 2) additional expenses within wood industry on adjusting the capacities to process higher supply of thin wood from sanitary cuttings;

- 3) losses of material during conversion of roundwood of smaller diameters (loss of about 5% of the total wood mass);
- 4) material losses during storage of roundwood (about 15% of total volume moves to the lower quality class);
- 5) losses of about 5% of sawn timber quality and increase of production costs due to the obligatory treatments and sterilization;
- 6) losses due to decrease of strength of sawn timber (about 10%); and
- 7) losses due to changes of the chemical composition of wood (e.g. in particle board production there would be a need for increased use of glues and lacquers).

Taking as a basis for calculations the current costs and prices, as well as present amounts of harvested roundwood and levels of production of given branches of wood industry (except of fibrous masses industry) the losses have been estimated for the whole country at 14 mld zł yearly.

The present estimation doesn't take into account all the losses (e.g. losses in fiber and paper mills). Therefore, the total losses due to changes of wood quality would be much greater than the data given above. It is estimated that the total losses would be double the given value.

5. SILVICULTURE METHODS IN FORESTS AFFECTED BY INDUSTRIAL EMISSIONS

The urgent problem of decline of pine and spruce stands in some mountainous areas as well as the phenomenon of forest damages over big areas encountered in other parts of Poland necessitate the development of specific methods in managing forests of different rate of damage and in dependence on type and concentrations of toxic substances, species structure, site conditions etc.

Forests should fulfil various tasks and therefore it is necessary to apply various methods of management in different parts of their range. Taking into consideration different functions of stands methods for management of damaged forests can be presented as in the enclosed scheme (Fig. 4) [3].

According to the scheme stands located in zones II and III ought to be reconstructed at once, at first place - during the next two decades.

The following order of reconstruction is recommended:

1. stands in the regeneration class;
2. clear cut stands;
3. second-order clear cut stands;
4. cultures and thickets;
5. stands of medium age classes; and
6. stands with the share of deciduous species exceeding 20%.

The so-called total reconstruction should be applied to the clear cut stands in zone III and II. This requires intensive soil cultivation (adapted to local habitat conditions), liming (to help soil toxicity), fertilizing with mineral, and if possible, organic fertilizers (to prevent soil degradation) and artificial regeneration with a change in the species composition.

The conversion of species composition in the rest of stands should be carried out in the way of underplanting of deciduous trees in nest where dead wood was removed or where the selection cutting of higher trees was partially completed.

Cultures and thickets with signs of serious damage brought about by industrial pollution, a strong infestation by pests, and the stand density index of 0.7 or lower, should be removed and reforested with desirable species.

In areas affected by industrial emissions it is necessary to improve the accessibility of nutrients for the deciduous species introduced on poor coniferous forest sites by placing a thick layer of peat mulch under each nursery-grown plant, applying benitonite or fertilizing.

Particular attention should be paid to the tending cutting in younger stands. In the case of areas under the impact of heavy industrial pollution the chief task of cutting is the improvement of the sanitary condition of forests.

In any case, in regions threatened by industrial pollution, there is the necessity of an individual approach to particular stands as signs of changes

appear (e.g. excessive self-thinning of dead wood) - in each stand specific silviculture measures should be planned and applied.

6. HARVEST MECHANIZATION & COSTS

Performing the production tasks in domain of wood harvesting should be strongly linked with maintaining a possible good sanitary condition of forests, especially, while facing a heavy industrial pollution. On the other hand, one who is choosing a machine system must take into account the need for minimizing the harvesting costs.

Within the study an optimization model of machine system performance under different natural and organization conditions has been elaborated. The evaluation of current forest machinery structure for the whole Poland and calculations of desired structure allowing performance of wood harvesting in healthy and damaged forest have been carried out with the use of the model.

It has been revealed, that a change of existing, unfavorable forest machinery structure is essential. It is necessary to increase the number of light chainsaws by at least 20% and diminish significantly the number of heavy and medium chainsaws (by 4 times). The number of special forest tractors (mainly forwarders) should be increased by 80% as well as number of heavy road trucks - twice, while the total number of medium road truck has to diminish to some extent.

7. FORECAST OF CHANGES IN WOOD INDUSTRY STRUCTURE UP TO 2020

The study has revealed, that the main determinant of wood industry development is potential wood supply, since expressed demand for wood products in Poland is much higher than existing forest resources could satisfy. Therefore, the forecast regarding changes in wood industry structure was elaborated in two variants corresponding to the two versions of potential wood supply. In Fig. 5 dynamics of wood raw material consumption for basic products up to the year 2020 in comparison with 1986 year has been presented.

According to the obtained results from the studies, the following changes in wood industry are forecasted:

1. liquidation of old, unprofitable and badly situated in respect to raw material basis processing plants;

2. modernization of majority of processing plants (mills): - mechanization of heavy works;
 - increase of output of raw material (e.g. by gluing, aggregate wood conversion);
 - introduction of installations enabling amelioration of wood wastes for fibre industry;
 - development of production potential enabling so-called "deeper" wood conversion;
 - increase of production capacities of conversion into sawn materials of the thin wood (pulpwood type);
 - introduction of new technologies: (a) not harmful to environment, (b) increasing a quality of products, (c) decreasing raw wood material losses, (d) wider use of lower quality and value wood;
 - introduction of new products (such as MDF boards, cement bonded particle boards, new types of plywood)
3. significant increase in production (modernization and new capacities) of wood particle boards and fibrous masses
4. development of reserve capacities in case of wood oversupply or some wood commodities oversupply.

8. POLICY CONSIDERATIONS

In order to undertake a detailed examination of the management strategies that the forest-sector policy-makers could pursue to improve the condition of Polish forests at the same time as maintaining a healthy wood industry and meeting the domestic demand for wood products as much as possible, a workshop based on "policy exercise" formula, is being organized (Warsaw, November/December, 1988). Scientists and policy-people will be brought together for intensive interaction and mutual learning about shared problems. For the purpose of the policy game two scenarios (an optimistic and a pessimistic) describing possible future events within forestry and wood industry sector will be prepared. The participants to the policy game will be: forestry managers (16 people), wood industry managers (4 people), central administration (5) and public (2) representatives. During the policy exercise, each policy-group, in view of conditions posed in the scenario, will formulate their strategies for a given decade (up to 2020).

Concerning the results of the study, we plan to produce two monographs, one in English and one in Polish, including the background technical papers, the scenarios for the policy workshop, and conclusions drawn from the workshop and the whole study.

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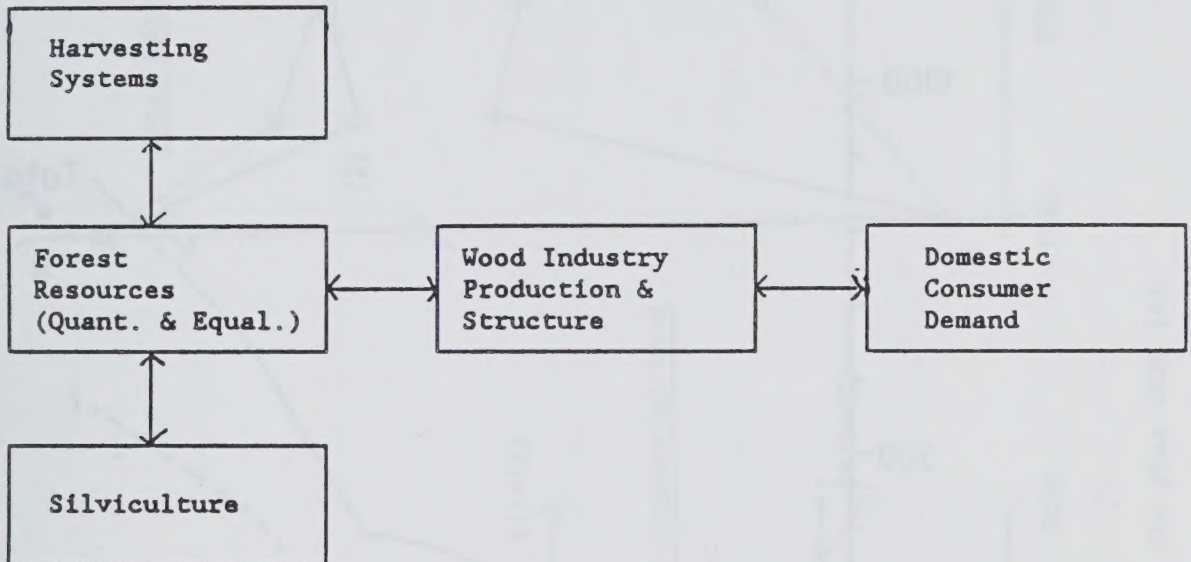


Figure 1. Structure of the study on the impacts of forest decline on future wood supply and industrial utilization of wood in Poland up to the year 2020.

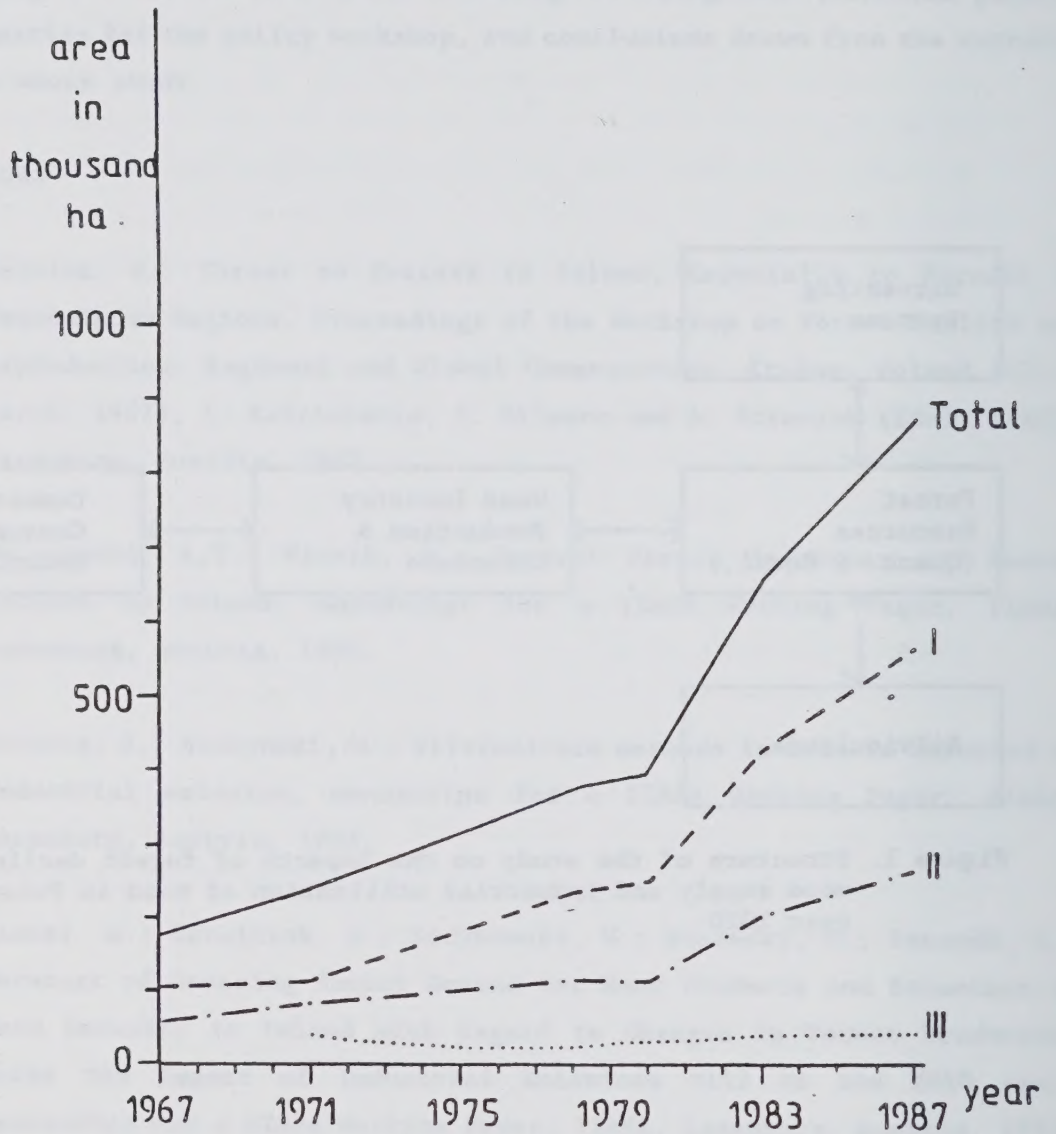


Figure 2: Dynamic of threat zone areas increase as well as of total forest area affected by air pollutants in Poland for the years 1967 to 1987 (according to data of the National Board of the State Forest Enterprises) (after [3]).

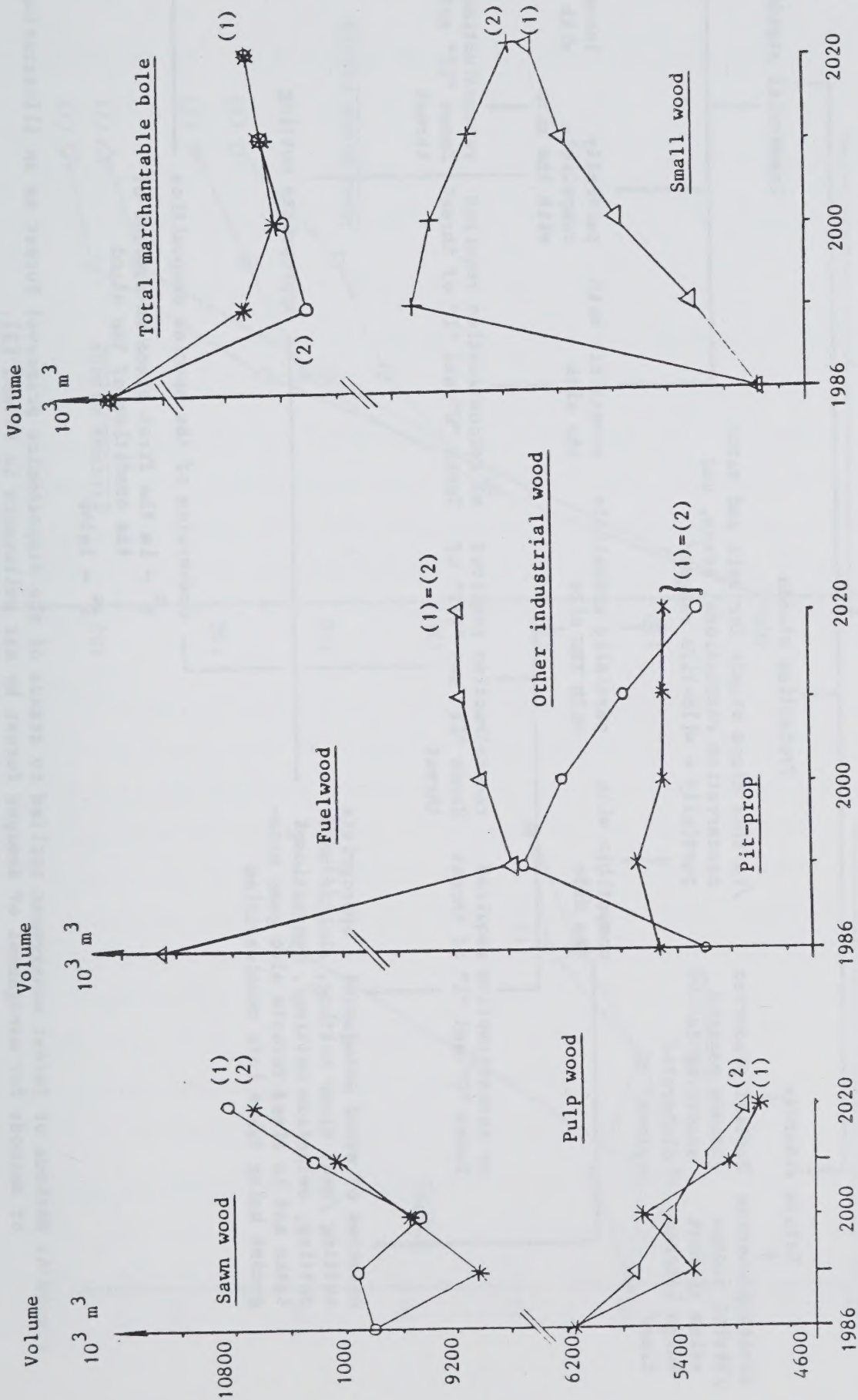


Figure 3: Forecast of wood commodities supply in Poland till the year 2020 [4].
 Notation: (1) variant (I) optimistic and
 (2) variant (II) pessimistic.

Stands of the Niepotomice Primateval Forest

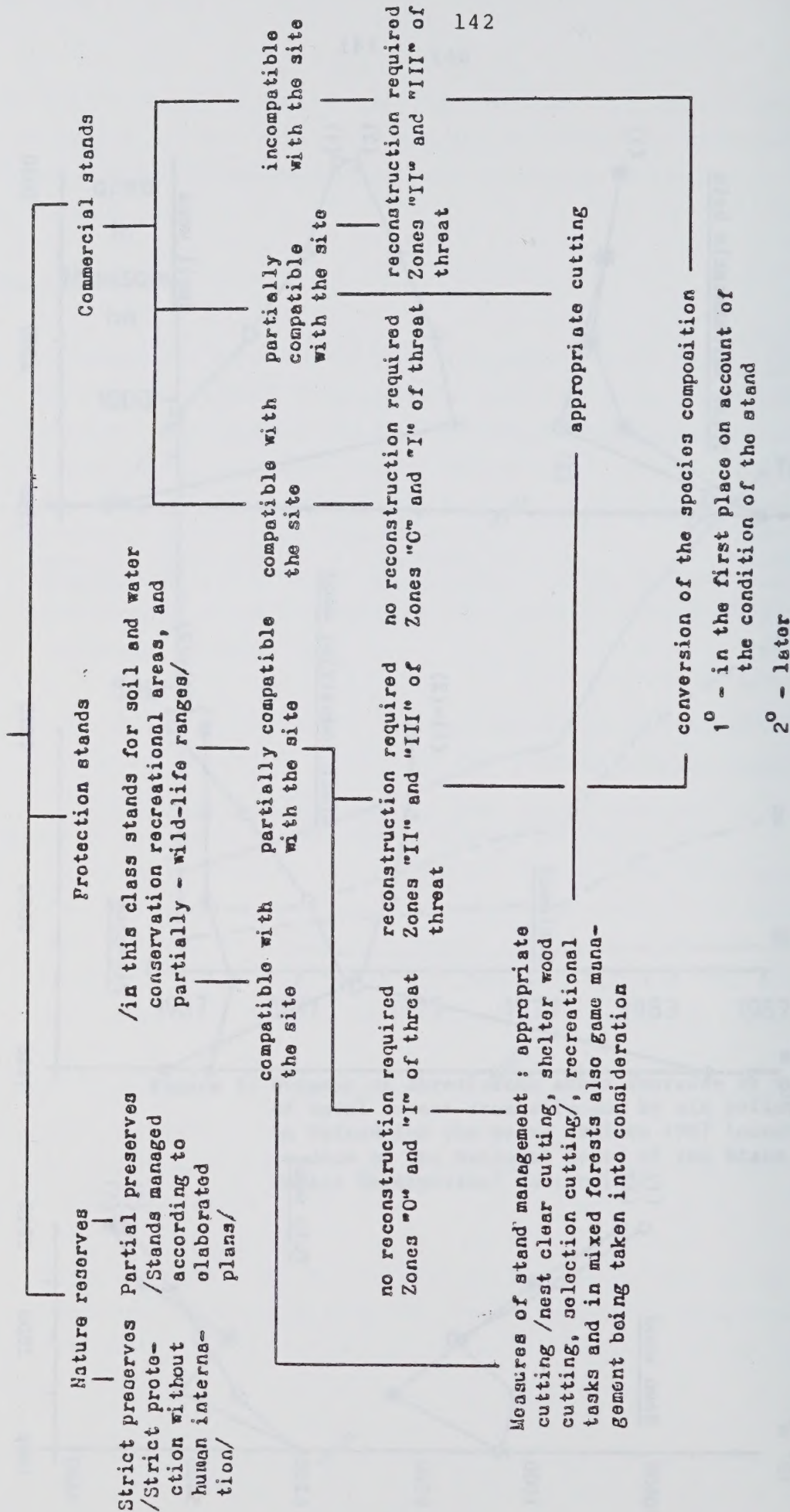


Figure 4: Methods of forest management applied to stands of the Niepotomice primeval Forest as an illustration of methods for management of damaged forest by air pollutants in Poland [3].

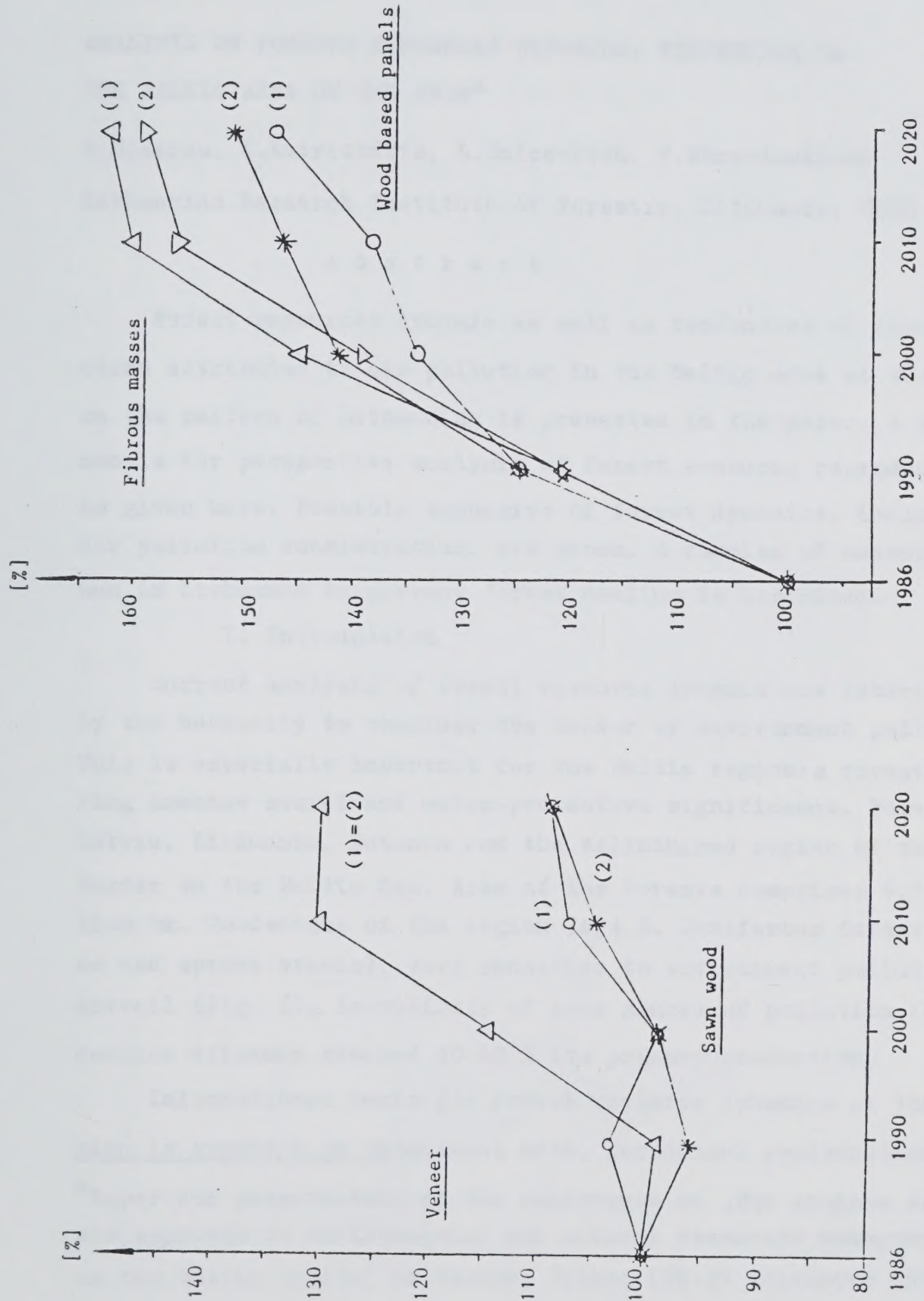


Figure 5: Prognosis for dynamic of increase of wood raw material consumption for basic wood products in Poland till the year 2020 [3]. Notation: (1) variant (I) optimistic and (2) variant (II) pessimistic. Note: data of 1986 stands for 100%.

ANALYSIS OF FORESTS RESOURCES DYNAMICS; TENDENCIES IN THE BALTIC AREA OF THE USSR¹

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Lithuanian Research Institute of Forestry, Lithuania, USSR

A b s t r a c t

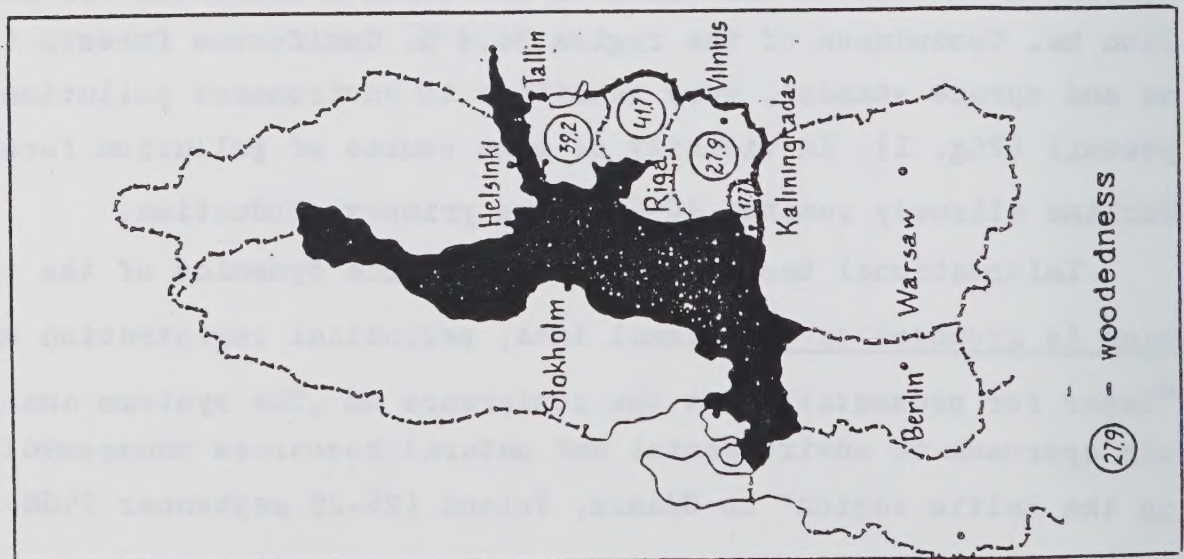
Forest resources dynamic as well as tendencies of forest decline attributed to air pollution in the Baltic area at the USSR on the pattern of Lithuanian is presented in the paper. A set of models for perspective analysis of forest resource reproduction is given here. Possible scenarios of forest dynamics, including air pollution consideration, are shown. A complex of measures taken in Lithuania to prevent forest decline is described.

I. Introduction

Current analysis of forest resource dynamic was interrupted by the necessity to consider the factor of environment pollution. This is especially important for the Baltic region's forests having immense social and water-protective significance. Forests of Latvia, Lithuania, Estonia and the Kaliningrad region of the RSFSR border on the Baltic Sea. Area of the forests comprises 6,5 million ha. Woodedness of the region 34,4 %. Coniferous forests (pine and spruce stands), very sensitive to environment pollution, prevail (Fig. I). In vicinity of some source of pollution forest decline already reached 40-60 % its primary production.

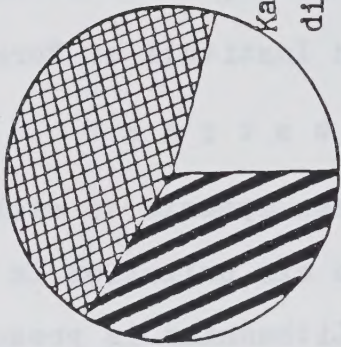
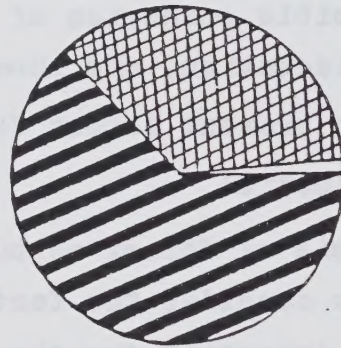
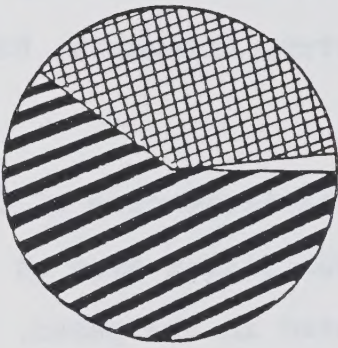
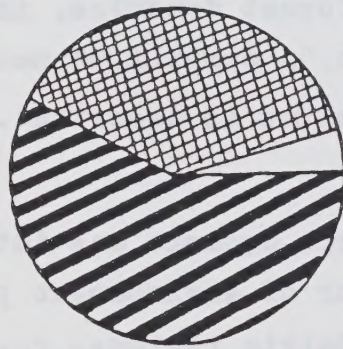
Informational basis for forest resource dynamics of the region is grounded on taxational data, periodical registration and

¹Paper for presentation at the conference on „The systems analysis approach to environmental and natural resources management in the Baltic region" in Gdansk, Poland (26-29 september 1988).



Lithuanian SSR

Latvian SSR



Estonian SSR

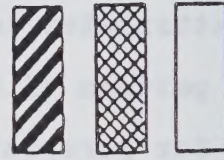
Kaliningrad
district

Fig. 1. Woodedness and tree species distribution in the Baltic area of the USSR

forest monitoring. For long-term prognostication of possible forest dynamics' variants a set of models is implemented.

On the pattern of the Lithuanian SSR the present state of forest environment pollution, some approaches to forest resource dynamics' modeling, possible tendencies of the dynamics and measures for preventing forest dying are presented in the paper.

2. Environment pollution

Ecological situation in Lithuania has taken an unfavourable turn. The republic has the greatest anthropogenic loading on environment. According to statistical data permanent sources throw out about 0,5 mln. tons of harmful substances yearly. The structure of substances thrown from permanent sources into the atmosphere of Lithuania is following: sulphur anhydride (46,4 %), carbon oxide (20,8 %), nitric oxide (8,8 %), carbon hydrogens (8,2 %) and solid substances (dust), (11,5 %), (data of 1986). Almost as much pollutants are thrown by motor transport. Pollution from permanent sources has stabilized, but pollution by motor transport is going to increase.

Along with „native“ sources pollutants coming from west-European countries influence atmospheric contamination of the republic either. Every year more than 800 tons of sulphur are brought on the territory of the USSR from Poland and GDR. Under the prevailing west wind a significant amount of it is brought to Lithuania. Background concentration of SO_2 in Lithuania has already reached 0,015-0,035 mg/m^3 / 1 /. Pollution from air passes over to forest soils. There are hardly left any unpolluted waters in the republic. Under the impact of antropogenic factors a tendency of increased area of dead and damaged forests due to environment pollution is traced. About 1 thou. ha of stands are already dead, 10 thou. ha are damaged, 200 thou. ha of forests grow in dangerous industrial zones / 2 /, (in Lithuania forests make up 1,8 mln. ha).

3. Assessment of forest decline by dendrochronological methods

In the meantime dendroclimatological methods of investigation of forest decline have been applied on a larger scale. With the aid of dendroindication it is easy to determine of wood increment losses attributed to environmental pollution by industrial emissions.

During investigations of annual radial increment dynamics in spruce stands (*Myrtillosa*; site type L_c) exposed to long-term (since 1968) local contamination by industrial emissions we have carried out dendroclimatological analysis of annual increment losses. Three different methods have been worked out.

One control method, when dendrochronological indicies of polluted and unpolluted stands have been compared. As the control a stand growing apart from the polluted area but having the same taxational indices analogous to the experimental stand (before pollution appeared) has been selected.

Until the source of contamination - appeared, fluctuations of radial increment indices followed according to rhythm of 11-year duration caused by the dynamics of climatic background (Fig. 2). Under the influence of air pollution increment dynamics demonstrated difference; e.i., instead of maximum in the control stand in 1973-1976, minimum was revealed in the damaged stand beginning with 1968 year. This is explained by constant negative impact of industrial emissions which in 1976 have reached its maxima. In this period spruce radial increment in the zone of intensive pollution has decreased by 40-60 %, while in the vicinity of the pollution source it has reduced even by 70 % as compared with the control. According to our calculations annual increment losses of damaged middle-aged stands amount to 2-2,5 m³/ha.

It is not an easy task to select control stands because of absence of unpolluted stand in large region due to long distance environmental pollution impact on forest ecosystems. Therefore, it is purposeful to implement the so called method of standard

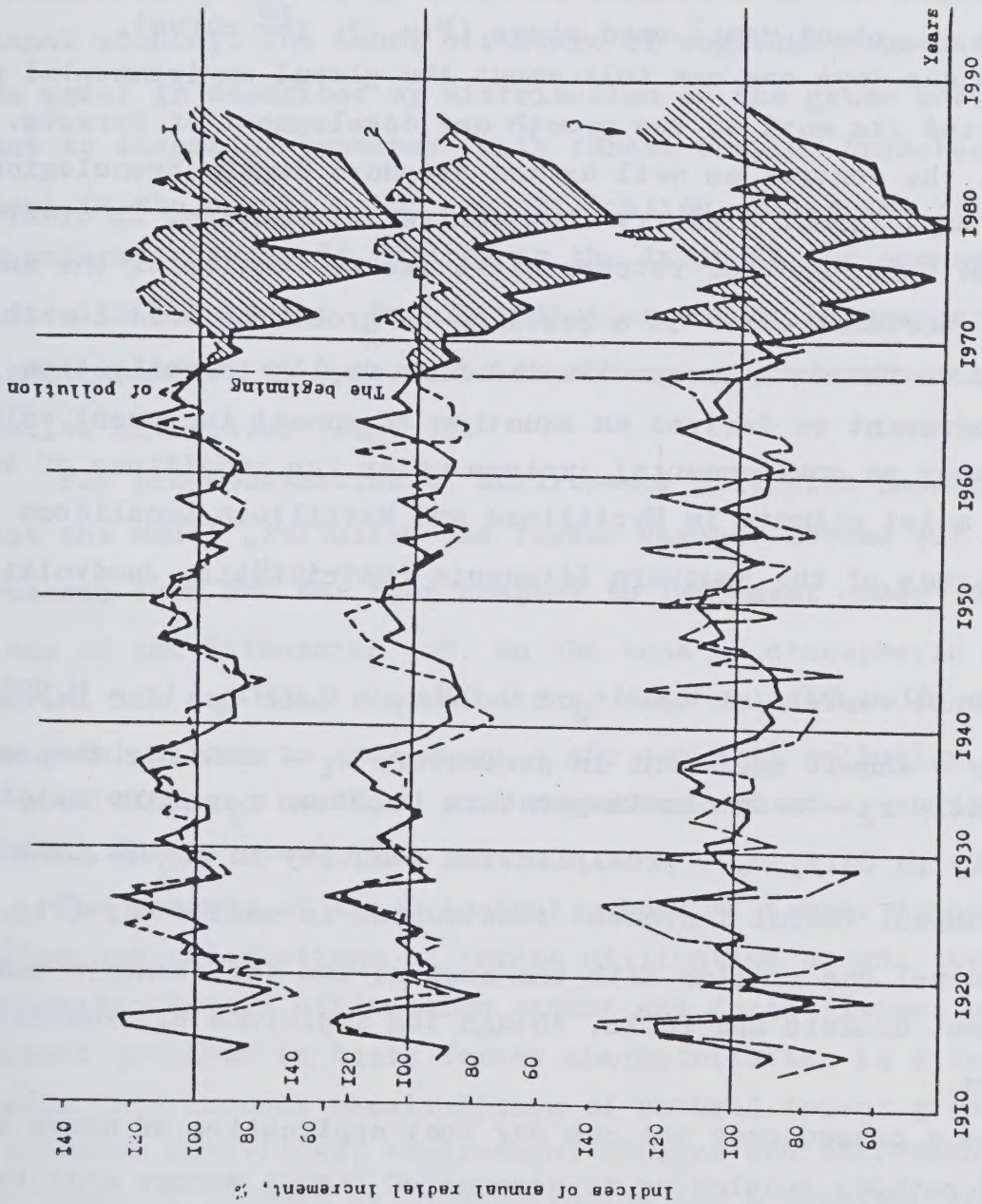


Fig. 2. Dynamics of annual radial increment indices in Myrtillosa spruce stands in the zone of severe pollution (---): 1 - control; 2 - the curve of the standard dendrochronological scale; 3 - increment curve reconstructed on the base of climatic indices using the formula $y = -0,36I - 0,003x_1 + 0,024x_2 + 0,001x_3 + 0,004x_4$; /// - increment loss.

dendrochronological series. In this case as a base line of tree growth (control) serves the standard scale of annual radial increment indices. For Myrtillosa spruce stands we constructed the standard chronology on the data base of 100 experimental trees. This dendrochronology has been used as a control. Differences between the values of indices of the damaged stand and the standard chronology during the years of pollution outbreak (1968-1987) - increment loss - insignificantly differs from that using the control stand mentioned above (Fig. 2. 2nd curve).

In our days one can talk about the global environmental pollution and its mark on the growth and development of forests. Therefore, the control as well as the standard dendrochronological method may present a partly inobjective information. In order to overcome this, and for retrospective reconstruction of the annual radial increment curve as a baseline of growth we used the third method. On the data base collected from daily investigation of tree increment we derived an equation of annual increment values dependency on environmental factors under the conditions of temperately moist climate in Myrtillosa and Myrtillosa-Occalidos type pine stands of the southern Lithuania (Kairiūkštis, Juodvalkis, 1972):

$$y = -0,361 - 0,003x_1 + 0,024x_2 + 0,001x_3 + 0,004x_4 \quad (r = 0,993)$$

where y - annual increment in perimeter; x_1 - mean air temperature in MAY; x_2 - mean air temperature in June, x_3 - precipitation quantity in July; x_4 - precipitation quantity in August. The curve of annual radial increment constructed in such a way (Fig. 2; 3rd curve) has similar with the control and the standard scale increment ascents and falls, though the amplitude of fluctuations differs.

As a consequence one can say that application of above mentioned methods enabled us to assess of forest damage attributed to environment pollution.

4. A set of models for analysis

Analysis of the tendency of forest resource dynamics is performed by using a complex of models: for regional reproduction, pollution impact on forest, prognostication of complex forest utilization and oth. The model of regional reproduction worked out at the Institute of economics of the Academy of Sciences / 3 / contains imitation of development scenarios of the republic's national economy. The inner structure of regional reproduction in the model is described by distribution of the gross national product to dozens of branches (with forest complex branches among them) in the direction of its utilization. While the reflection of natural changes is related to the intensity of economic activities in the region. Nature pollution extent (atmospheric emissions included) is determined depending on productive and unproductive activities (Fig. 3).

For prognostication of environment pollution impact on forest the model „Pollution and forest damage" worked out by W.-D. Grossman from FRG has been adapted to implement under the conditions of the Lithuanian SSR. On the base of atmospheric pollutants, initial air and soil contamination, area and forest description, the model allows to characterize air and soil pollution, changes of wood biomass, needles, soil organisms and other indices reflecting forest state (Fig. 4).

The essence of the principal scheme of forest dynamics' modeling and calculations of forest utilization extent lies in the following: forest utilization extent and forest impact on environment grounded on basic forest characteristics is determined; taking into account peculiarities of natural forest growth, silvicultural activities, environment changes and accidental factor the state of forests is prognosticated for a ten-year period and then calculation are repeated. This scheme is partly realized in the model of complex forest utilization forecasting. The input information of the model contains data on forests of the republic. The data is differentiated to economic branches formed according

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1500

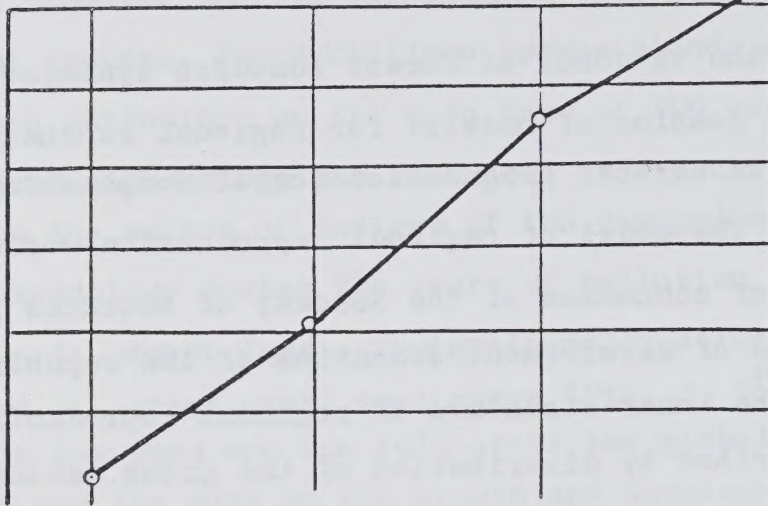
1400

1300

1200

1100

1000

Atmosphere
protection
funds

400

300

200

100

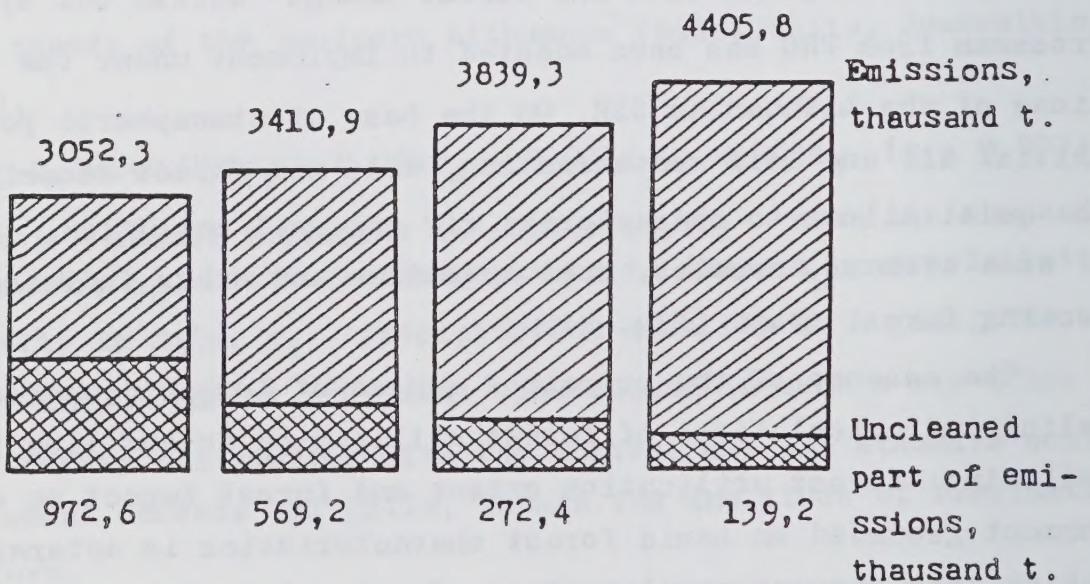
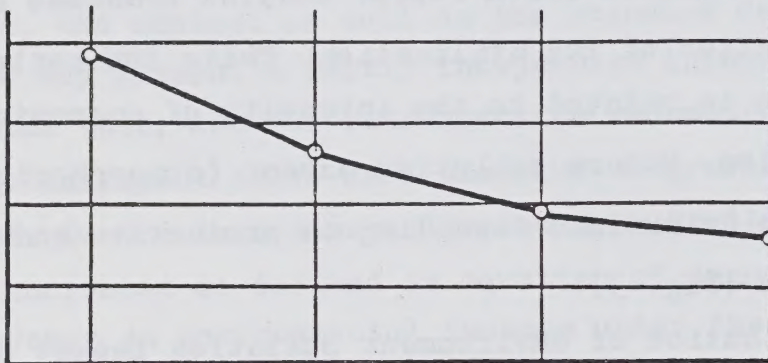
Damage from
air emissions

Fig. 3. Tendency of volumes of air-emissions depending on the increase of atmosphere-protection funds

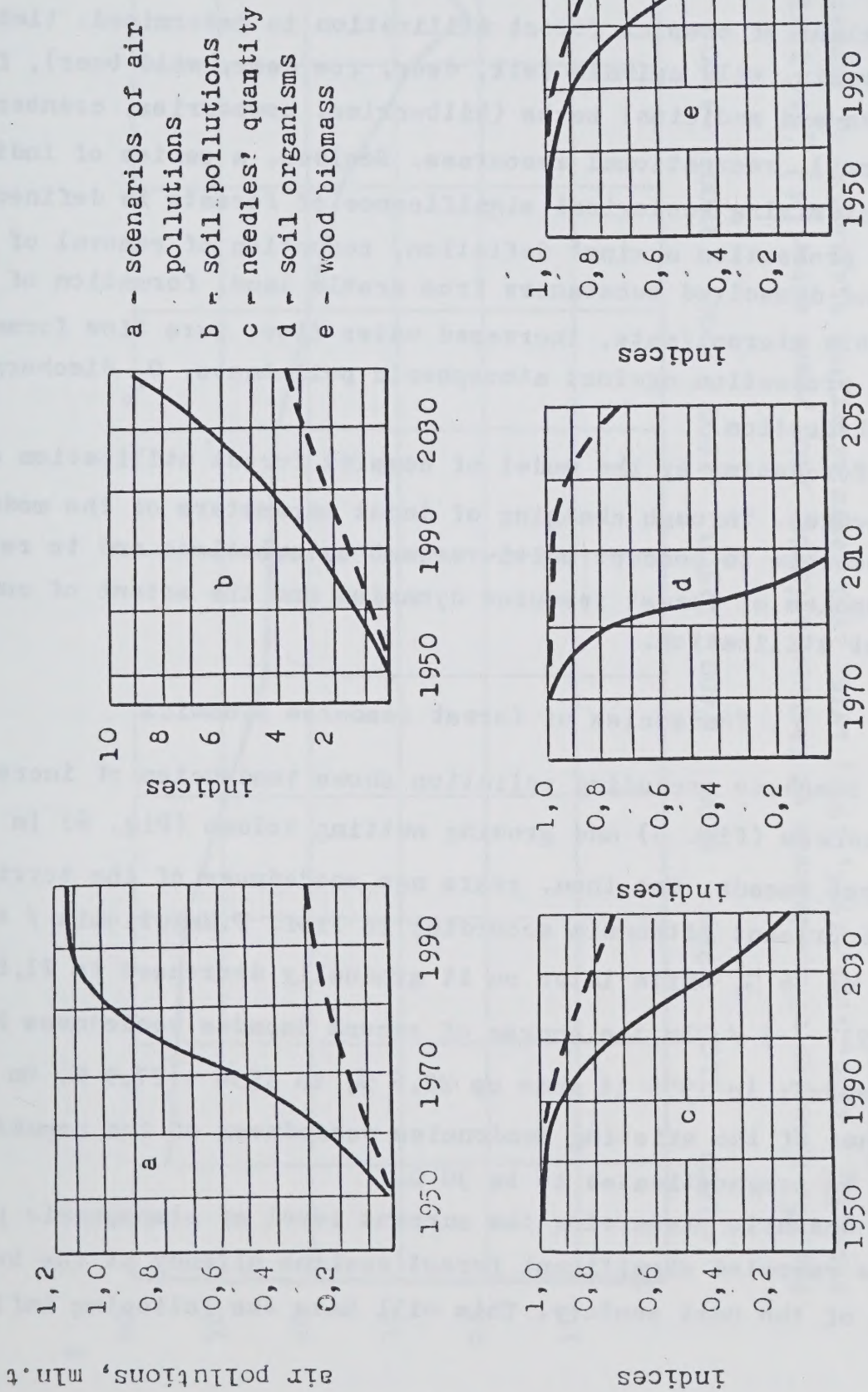


Fig. 4. Indices of influence of air pollutions on forest

to the special-purpose of forests (forests of special assignment, protective, exploitative, agricultural forests and oth.). Most data used in the model (area and growing-stock, area of forest berries and oth.) is additionally differentiated according to the dominating tree species and site type. In the output of the model extent of complex forest utilization is determined: timber, tree resin, wild animals (elk, deer, roe deer, wild boar), forest berries and medicinal herbs (bilberries, cowberries, cranberries, berry), recreational resources. Besides, a series of indices characterizing ecological significance of forests is defined: field protection against deflation, reduction of removal of solid and dissolved substances from arable land, formation of favourable microclimate, increased water flow, pure flow formation, field protection against atmospheric pollutants, O_2 discharge, CO_2 absorption.

Forecasting by the model of complex forest utilization covers 13 decades. Through changing of input parameters of the model it is possible to conduct multi-variant calculations and to reveal tendencies of forest resource dynamics and the extent of complex forest utilization.

5 . Tendencies of forest resource dynamics

Scenario excluding pollution shows tendencies of increasing woodedness (Fig. 5) and growing cutting volume (Fig. 6) in the nearest decade. One thou. years ago woodedness of the territory of present Lithuania according to Prof. P. Matulionis / 4 / made up 56 %, while later on it gradually decreased to 21,8 % in 1937 / 5 /. In the course of recent decades woodedness has increased: in 1956 it made up 22,6 %, in 1938 - 27,9 %. On the account of the existing tendencies woodedness of the republic by 2020 is prognosticated to be 30 %.

Scenario preserving the current level of atmospheric pollutants revealed significant forest decline already at the beginning of the next century. This will have the following influ-

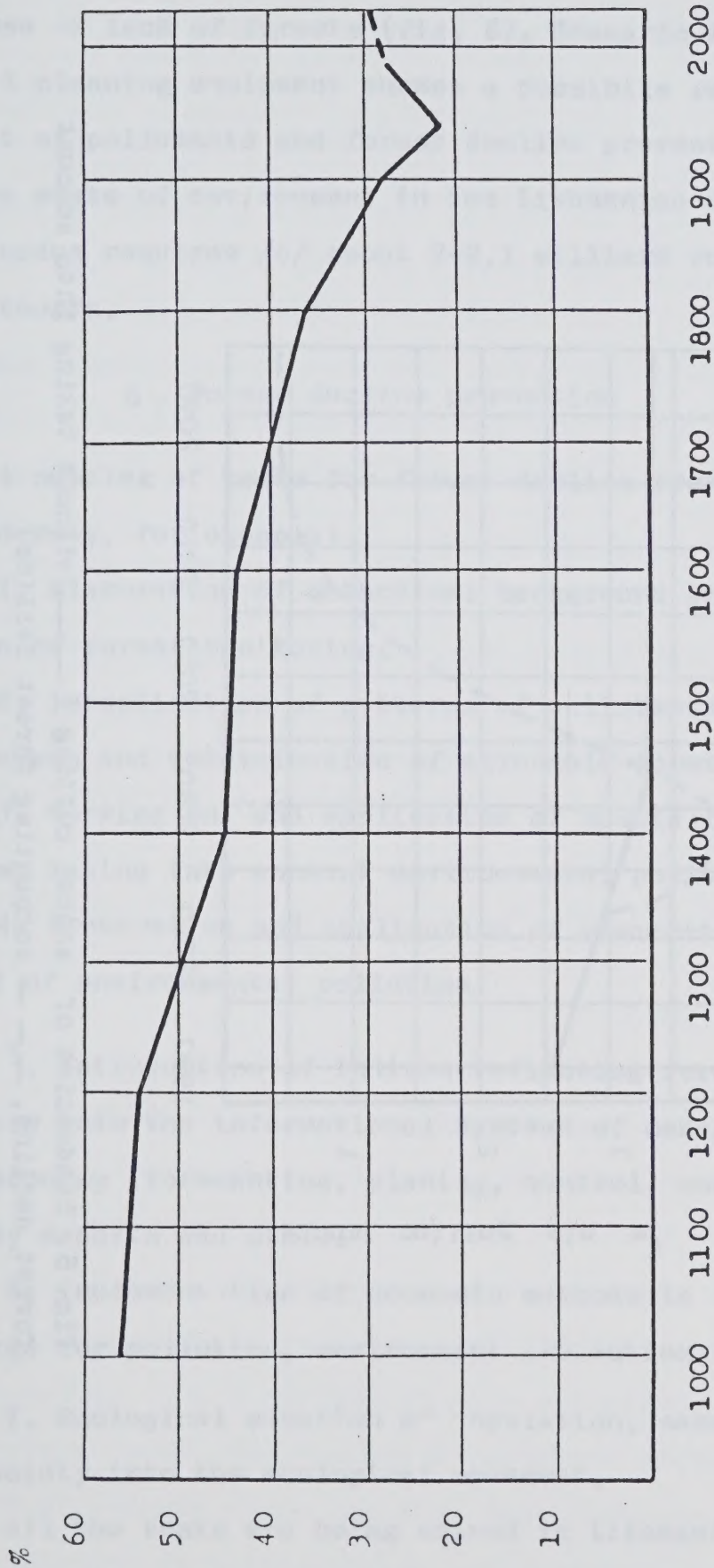


Fig. 5. Dynamics of woodedness of Lithuania (under 1900 years after [4] , in 1937-year after [5] , 1956, 1961, 1966, 1973, 1978, 1983 years after the statistics of forest, — — — forecast).

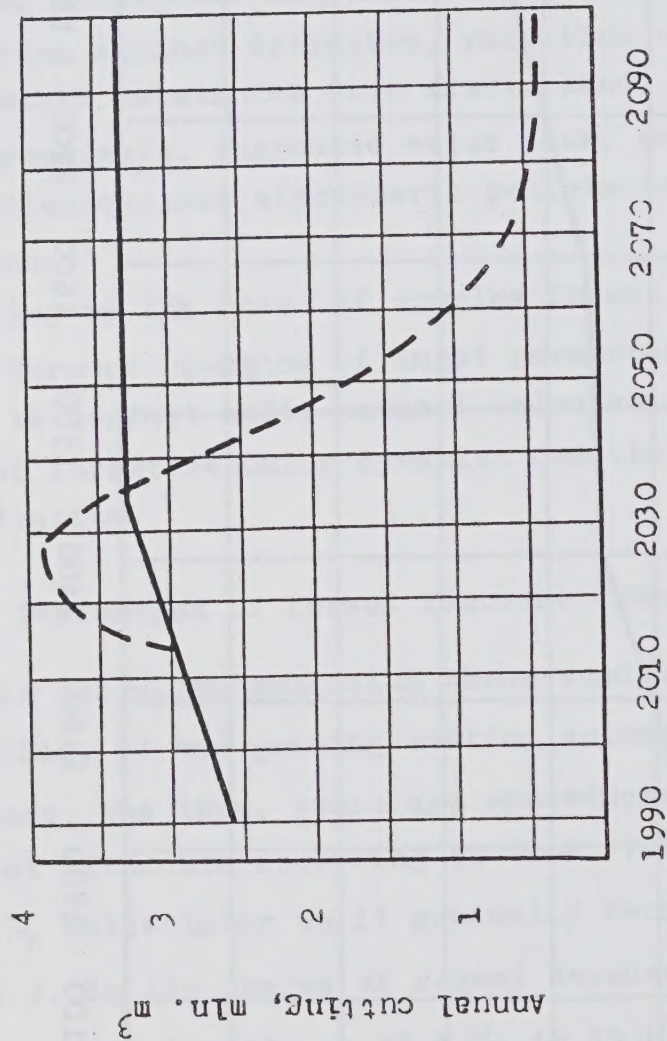


Fig. 6. Tendencies of annual cutting (——— without taking into account forest decline, - - - accounting forest decline)

ence on the extent of harvesting: at first an increase in amount due to the necessity to cut out dead trees and then reduction because of lack of forests (Fig. 6). Scenario introducing additional cleaning equipment shows a possible reduction in the amount of pollutants and forest decline prevention. Perfection of the state of environment in the Lithuanian SSR for the nearest 20 decades requires /6/ about 2-2,1 milliard roubles of capital investments.

6. Forest decline prevention

A complex of tasks for forest decline prevention currently is underway, for example:

1. Elaboration of methodical background and practical application of forest monitoring.
2. Investigation of patterns of pollutants' impact on forest ecosystems and determination of allowable forest pollution level.
3. Working out and application of specialized silvicultural systems taking into account environmental pollution.
4. Preparation and application of measures to reduce the level of environmental pollution.
5. Introduction of indices reflecting forest ecological factors into the informational systems of management of national economy (forecasting, planning, control, ecological appraisal by experts and oth.).
6. Implementation of economic methods in forest protection (charge for pollution, environment protection funds and oth.).
7. Ecological education of population, mass involvement of society into the ecological movement.

All the tasks are being solved in Lithuania as well as in others Baltic region republics and the initial results have already been reached.

For forest state assessment and prognostication under the conditions of pollution-exposed environment of the Lithuanian SSR forest monitoring activities are carried out. Laboratory of Forest Monitoring was set up in the Agricultural Academy of Lithuania, the Lithuanian Research Institute of forestry performs the function of national centre in the International Program of assessment and observations on atmospheric pollutants' impact on forests, the Lithuanian Forest Regulation Office has begun practical implementation of monitoring in the forests of the republic. The program of works according to forest monitoring includes elaboration of methodical and organizational background for regional forest monitoring on the European part of the U.S.S.R., working out of preliminary standards of maximum allowable concentrations of toxic substances in the atmosphere, elaboration of physiological and biophysical, dendrocronological and micromorphological methods of early diagnostics of tree reaction to physical and chemical changes of the surrounding environment, preparation of network of permanent forest state observation stations, working out of models for forest resource reproduction and utilization taking into account the data of ecological monitoring.

According to the preliminary data on 1/3 of the republic's territory signs of tree-damage have been noticed in the greater part of forests (50-60 %).

Some patterns of pollutants' impact on forest ecosystems have been studied. Namely, patterns of tree-ring variance in the polluted environment bearing in mind natural ecoclimatic background fluctuations have been determined / 7 /. The ability of young pine stands (10-20 years) to endure significant concentrations of air pollutants is revealed / 8 /. A model of productivity dynamics of damaged stands has been worked out / 9 /. In the Lithuanian Forest Research Institute a project for forest reproduction by growing more gas-resistant wood and shrub species (M.Vaičys and oth.) has been constructed, peculiarities of cleaning cuttings

and other silvicultural activities on the polluted territories are being studied.

However, it was generally acknowledged that saving of forests lies in reduction of harmful pollutants. Much work has to be done in the sphere. The main directions of it-cleaning equipment and improvement of technological processes.

What concerns social-economic measures, methods for perspective analysis of environmental pollution consequences on forests has been worked out, an ecological appraisal by experts on planning industrial objects has been introduced. Governmental resolutions foresee charges for atmospheric pollution and formation of regional ecological funds.

This complex of measures assisted by international cooperation in the sphere of nature protection should help to prevent forest decline in the Baltic region.

S u m m a r y

Forest decline due to environment pollution has begun in the Baltic region of the USSR. Only in the Lithuanian SSR about 1 thou. ha of stands are dead, 10 thou. ha are damaged, 200 thou. ha of forests are faund in dangerous industrial zones.

The analysis of forest resource dynamics is based on a complex of models: regional reproduction, pollution impact on forests, complex forest utilization forecasting and oth. The basic scenarios of forest dynamics on the pattern of Lithuania are: 1) with pollution excluded it reveals a tendency of increased woodedness and growth of cutting volume; 2) if the present state of atmospheric pollution is preserved for the future, it shows a significant decline of forests already at the beginning of the next century; 3) if additional cleaning equipment is introduced, it demonstrates a possible forest decline prevention due to abundant capital investments.

The main measures for forest decline prevention in the Lithuanian SSR are: forest monitoring, investigation of patterns of pollutants' impact on forest ecosystems, elaboration of specialized silvicultural systems taking into account environmental pollution, improvement of cleaning equipment and industrial technological processes, a complex of social-economic measures (ecological appraisal by experts, control, charges, ecological funds, social movements, etc.).

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FISHERING

FISHERING

Game theoretic analysis of the management of a divided fishery

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Abstract. We consider game theory models of non-cooperative and cooperative management of divided fishery resources. Each subfishery is managed exclusively by one country. Non-cooperative game models are used to describe situations, where the countries fail to communicate or cannot agree on joint management policies. Cooperative games are used in studying jointly efficient resource management policies. We show that the management of a jointly owned resource will produce an inefficient result: the potential productivity of the resource and the economic revenues of the agents are lost during short term competition by the two countries. Division of the resource into two subfisheries, where each agent has access to only one of them, decreases the intensity of competition in resource harvesting. The number of different noncooperative games arising in a divided fishery setting is, however, large. This is shown to depend on the population dynamics of the resource, the information and the policy variables available to the countries during the joint management of the resource. The most efficient non-cooperative solution is reached, when the countries use harvest rates as policy variables during negotiations. This study revealed many important problems in the economic theory of exploitation of interdependent international marine resources, which have, so far, received minor attention in the literature. An example related to a transboundary Baltic herring fishery is used to illustrate the game theory approach to international resource management.

1 Introduction

In this paper we consider some theoretical and practical optimization and gaming problems which occur in the cooperative and non-cooperative management of marine resources. In particular, we consider a fishery which is divided into two interdependent restricted access subfisheries each of which is exploited by a sole-owner.

From the practical point of view the management of transboundary or divided fisheries is currently of great interest. This is due to the fact that there exist organizations or multilateral negotiations representing neighbouring coastal states the purpose of which is to manage and regulate the use of transboundary resources. So far, there has not been a sufficiently well developed and realistic theory to support the decision making. One of the aims of this paper is to contribute to the development of such a theory or methodology.

In the literature there is a growing trend to use dynamic game theory models in resource management problems, see e.g. [2], [4-6], [9-13]. However, there are only a couple of applications dealing with transboundary fisheries. Munro [12] considered co-operative management policies in a fishery where the access of the countries to the resource is unrestricted and where the countries negotiate a binding agreement related to the utilization of the resource. On the other hand, Clark [2] showed that when binding agreements are not available two or more non-cooperative countries harvesting the same resources will miss the potential economic revenues from the fishery due to the lack of their mutual cooperation.

Kaitala and Hämäläinen [10] introduced a simple duopoly model to show that efficiency of non-cooperative harvesting can be increased if the countries divide the resource into two exclusive fishing zones (see Fig. 1). Each country have access only to its own fishing zone, and they harvest same or interdependent resources. Besides affecting each others' activity through the interdependence of the subfisheries, the countries also interact through the communication process, such as negotiations etc. This is a typical situation in the fisheries in the Baltic Sea, e.g. in the fisheries in the Gulf of Finland. However, efficiency is reached in a divided fishery only when the two substocks are dynamically independent.

A game theory study of the choice of the policy variable shows that management by fish stock level, by fishing effort or by harvest rate each result in different Nash equilibrium strategies (see [6], [13]). In this paper, variables used in the management negotiations are called policy variables. The practical control variable used by the managers of the fishing need not be same as the policy variable in question. Harvest rate and fishing effort are possible control variables where as fish stock level is not. However, the use of stock level as a policy variable does not require that it is the direct

control variable. Within each fishery the desired stock level is reached, if possible, by controlling the fishing effort or harvest rate. Moreover, if we are dealing with open access fisheries in each country the desired stock level can be maintained by taxes and subsidies [1]. The management scheme that we propose and reaction curves related to each pair of policy variables determine a set of steady Nash equilibria. Secondly, a non-cooperative game is played to choose one pair of policy variables.

The game theoretic problems that arise in the modelling of multi-agent resource use are related to singular solutions, the infinite planning horizon and to the problems in the interdependence of the information structures and the solution concepts.

Mathematically we are dealing with non-linear nonzero-sum differential games and bargaining models. The questions of interest are: How should the sole-owner fleets react to different harvesting strategies of the neighbouring country. What is the role of information. How should the two sole-owners choose their policy variables in the negotiations dealing with the resource use. Indeed, the solution of the game depends on the policy variable chosen.

The paper is composed as follows. In the next section we present the basic system models describing the resource growth and interdependence of the substocks. Then we analyze the necessary conditions for the optimal singular steady state reactions of one player to fixed values of the policy variables of the other player. Finally, the negotiations about the management of the divided fishery by the two sole-owner fishing agencies are discussed and a two-stage game on the choice of the policy variable is studied. Throughout the paper we shall call the fishing agencies Country 1 and Country 2, although a game problem like this can occur equally well between two national fleets having neighbouring restricted access fishing grounds. This paper represents a further elaboration of the study of the model presented in [6].

2 The divided fishery game

Consider a fishery which is divided into two subfisheries, the interaction between which is modelled as a diffusion. The dynamics of the fish stocks are described by the following equations [6]

$$\begin{aligned} dx_1/dt &= F_1(x_1) - h_1 - \sigma(x_1 - x_2), \\ dx_2/dt &= F_2(x_2) - h_2 - \sigma(x_2 - x_1), \\ h_i &= q_i E_i x_i, \quad i, j = 1, 2, i \neq j, \end{aligned} \tag{2.1}$$

where x_i is the biomass of the substock i , $F_i(x_i)$ is the growth function of the substock i , h_i is the harvest rate in subfishery i , E_i is the fishing effort in subfishery i , q_i is the catchability coefficient in subfishery i , and σ

is the diffusion coefficient. Clearly, when the substocks do not interact, then $\sigma = 0$. In this paper we assume that $\sigma > 0$.

We use the logistic growth curve for the entire fishery

$$F(x) = rx(1 - x/K),$$

where r is the intrinsic growth rate and K is the maximum stock level or the carrying capacity of the fishery. The development of this growth function for geographically and biologically uniform fishing grounds is based on the assumption that increasing the density of fish limits the growth rate. Thus to be precise x should be interpreted as the biomass of fish per unit area of the fishing grounds and K should be the carrying capacity per unit area. Generally these values per unit area need not be used because the area of the fishing grounds is constant. Hence, it is correct to write the natural growth functions of the subfisheries in the following way

$$F_i = rx_i(1 - x_i/K_i), \quad i = 1, 2,$$

where $K_1 = K_2 = K/2$. In the division into subfisheries the intrinsic growth rate remains the same as in the undivided fishery but the carrying capacities of the subfisheries are lowered proportionally to the sizes of the zones. The catchability coefficient increases, and we have $q_i = 2q$, $i = 1, 2$, where q is the catchability coefficient of the undivided fishery. The diffusion terms in (2.1) represent the net migrations of fish between the fisheries, which is assumed to be linearly dependent on the difference in the stock levels. The harvesting cost is a linear function of the fishing effort E

$$C_i(E_i) = c_i E_i, \quad i = 1, 2.$$

The cost can be expressed in terms of harvest rate by using the production function $h_i = q_i E_i x_i$:

$$C_i(h_i/(q_i x_i)) = \frac{c_i}{q_i x_i} h_i, \quad i = 1, 2.$$

We also denote

$$C_i(x_i) = \frac{c_i}{q_i x_i} h_i, \quad i = 1, 2.$$

The net revenue flow to the two fishing sectors is

$$\pi_i(E_i) = p_i q_i E_i x_i - c_i E_i, \quad i = 1, 2,$$

or equivalently

$$\pi_i(h_i) = (p_i - \frac{c_i}{q_i x_i}) h_i, \quad i = 1, 2,$$

where p_i is the price of fish received by fishermen in fishery i .

The parameter values used in the numerical simulation studies are as follows: $r = 0.46/\text{year}$, $K = 4 \times 10^5$ tons, $\sigma = 0.3/\text{year}$, $q_1 = q_2 = 9 \times 10^{-5}/(\text{trapnet year})$, $p_1 = p_2 = 920 \text{ FMK/ton}$, $c_1 = 3.276 \times 10^3 \text{ FMK}/(\text{trapnet year})$, and $c_2 = 5.9 \times 10^3 \text{ FMK}/(\text{trapnet year})$. These parameter values are estimated from data which represent the herring fishery of the Gulf of Finland in the Baltic Sea. This fishery is divided between the USSR and Finland. The two fishing fleets are operated under sole-owner and open access conditions which has given the initial motivation to analyze the game problem considered in this paper. The parameters are rough estimates but it is believed that they are at least of the correct order of magnitude.

3 Steady state Nash equilibrium strategies

In order to study the Nash strategies in the resulting resource games we need to solve the unilateral optimization problems. In this section we give necessary conditions for the optimal steady state reactions of a country when the policy variable of the neighbouring country is fixed and its value is given. For this purpose it is sufficient to assume that a country (say Country 1) has perfect knowledge of the population dynamics of the two subfisheries and of its own performance criterion. Country 1 can determine its optimal steady state solution for each value of the policy variable applied by Country 2. This defines the reaction curve of Country 1 with respect to the policy variable of Country 2 in question.

The both harvesting countries have three options in the choice of the policy variable to be used in the negotiations: stock level, harvest rate, and fishing effort. The reaction curve of a country depends on the policy variable chosen by the neighbouring country. In the following analysis we shall consider steady state singular solutions only.

Harvest rate reaction

First consider the optimal reaction of Country 1 to a constant harvest rate of Country 2. Country 1 maximizes

$$J_1 = \int_0^\infty e^{-\delta_1 t} (p_1 - C_1(x_1)) h_1 dt \quad (3.1)$$

subject to the constraints

$$dx_1/dt = F_1(x) - h_1 - \sigma(x_1 - x_2), \quad (3.2)$$

$$dx_2/dt = F_2(x) - h_2 - \sigma(x_2 - x_1), \quad (3.3)$$

where $C_1(x_i) = c_1/q_1 x_i$, $h_1 = q_1 E_1 x_1$, $0 \geq h_1 \geq h_{1max}$, and h_2 is a non-negative constant. We assume that the constraints imposed on the harvest rate are not active in the steady state solutions. Since in this optimization problem the policy variable h_2 of Country 2 is treated as a given constant parameter, the problem for Country 1 is an ordinary optimal control problem.

The solution to this optimization problem does not depend on the variable, which is chosen to be the formal control parameter in the mathematical solution. Thus, it does not matter whether we use the harvest rate h or the fishing effort E as the control variable. However, the situation is different when we determine the solution of the dynamic game as the intersection of the reaction curves. Then the policy variables do affect the solution. Thus, one should distinguish between the formal control variable which is used in the solution of the reaction curve and the policy variable used when announcing the reaction curve to the opponent in the game problem. The maximum principle is applied in developing the necessary conditions for the singular solutions. Here we shall omit the details but the basic techniques is described e.g. in [1]. In the above problem the necessary conditions for the steady state singular solutions are

$$\begin{aligned} F'_1(x_1^*) - \sigma - \frac{C'_1(x_1^*)(F_1(x_1^*) - \sigma(x_1^* - x_2^*))}{p_1 - C_1(x_1^*)} \\ = \delta_1 + \frac{\sigma^2}{F'_2(x_2^*) - \sigma - \delta_1}, \end{aligned} \quad (3.4)$$

and

$$F_2(x_2^*) - \sigma(x_2^* - x_1^*) = h_2 \quad (3.5)$$

where h_2 is the given constant harvest rate of Country 2 and the derivatives are denoted by a prime. The related optimal harvest rate h_1^* and fishing effort E_1^* are obtained from the equations

$$\begin{aligned} F_1(x_1^*) - \sigma(x_1^* - x_1^*) &= h_1^*, \\ E_1^* &= h_1^*/q_1 x_1^*, \end{aligned}$$

respectively, where x_1^* and x_2^* satisfy the equations (3.4)-(3.5). The necessary conditions yield implicit equations from which we can, at least numerically, determine a candidate for the optimal reaction provided it exists. It is clear that it can be given in three equivalent ways: $x_1^*(h_2)$, $h_1^*(h_2)$, and $E_1^*(h_2)$.

Fishing effort reaction

Next consider the necessary conditions of the optimal reaction of Country 1 to a constant fishing effort E_2 of Country 2. The problem for Country 1 is now the same as that defined above by equations (3.1)-(3.3), besides that the harvest rate h_2 of the opponent is known to be of the form $h_2 = q_2 E_2 x_2$, where E_2 is the given fishing effort of Country 2.

It can be shown in the same way as in the fixed harvest rate case that the steady state singular values x_1^* , x_2^* satisfy

$$F'_1(x_1^*) - \sigma - \frac{C'_1(x_1^*)(F_1(x_1^*) - \sigma(x_1^* - x_2^*))}{p_1 - C_1(x_1^*)}$$

$$= \delta_1 + \frac{\sigma^2}{F_2'(x_2^*) - q_2 E_2 - \sigma - \delta_1}, \quad (3.6)$$

$$(F_2(x_2^*) - \sigma(x_2^* - x_1^*)) / q_2 x_2^* = E_2$$

where E_2 is a given constant.

Stock level reaction

Finally, if the policy variable of Country 2 is the stock level, then from the point of view of Country 1 the stock level of the neighbouring zone can be regarded as a constant parameter. This means that the growth dynamics of the neighbouring fishery does not affect the solution of the optimal reaction. The problem for Country 1 is now

$$\max J_1 = \int_0^\infty e^{-\delta_1 t} (p_1 - C_1(x_1)) h_1 dt$$

subject to the constraint

$$dx_1/dt = F_1(x) - h_1 - \sigma(x_1 - x_2),$$

where x_2 is constant. The steady state singular solution x_1^* is now defined by

$$F_1'(x_1^*) - \sigma - \frac{C_1'(x_1^*)(F_1(x_1^*) - \sigma(x_1^* - x_2^*))}{p_1 - C_1(x_1^*)} = \delta_1, \quad (3.7)$$

In this formulation Country 1 does not utilize the growth dynamics of the neighbouring fishery. In the first two cases optimal reactions to fixed h_2 or E_2 take into account the effect of the dynamics of the neighbouring fish stock on the productivity of the "own" fish stock. This is accounted for by the additional second term that appears on the right hand sides of (3.4) and (3.6) compared to the pure discount factor of equation (3.7). It is clear that we get analogous equations for the reaction curves of Country 2.

In our analysis we have neglected the effects of the transients of the policy variables during the approach path. This can be interpreted so that we initially assume that the states are in the steady state values. The steady open-loop Nash solutions are obtained as the intersection of the steady state reaction curves. The existence is not proved in general as the intersections are found numerically.

The general solution to a nonlinear nonzero-sum infinite horizon differential game that we are dealing with is by no means straightforward. The approach paths or the stability of the solutions should also be considered. Haurie and Leitmann [7] have given sufficient conditions for the global asymptotic stability of bounded solutions in infinite horizon open-loop Nash games. However, due to the form of our system and criteria their results cannot be applied here.

4 Resource negotiations

Negotiation between countries about the utilization of natural resources can be realized in many ways, which depends on the goal of the negotiations and on the information available to the negotiators. In this section we consider the negotiations in which the policy variables to be used are chosen. We assume here that the cooperation cannot be guaranteed. Hence, the countries negotiate among the different equilibrium solutions available. By definition, an equilibrium solution is one where no country has any incentive to deviate unilaterally from it.

We assume here that the countries know the fishery dynamics and their own decision criterion perfectly, but nothing about the each other's decision criterion. This assumption is uncommon in Nash games, but does not seem to be very far from the practice of real resource negotiations. The assumption about incomplete information means that the agents cannot compute Nash equilibrium solutions independently.

Here we introduce a bargaining process, which includes two stages. First, the countries announce to each other their reaction curves with respect to different policy variables of the other country. This enables them to determine the nine steady state Nash equilibrium solutions. Second, a static game on the choice of policy variables is played. The question posed here is whether a country can affect the behaviour of the other country by announcing its strategies in different ways in the terms of the policy variables. Hence, the policy variable is used as a tool for delivering information during the bargaining process.

In the following we assume that for each pair of policy variables there exists a unique steady state Nash equilibrium solution. After the first stage of the negotiations the Nash points are known by both countries. Next, the countries need to evaluate the outcomes of the choice of the policy variables. In some cases the evaluation cannot be based directly on the present values of the total revenue. For example, when the discount rate is zero the value of the performance criterion in the infinite horizon optimization problem is not bounded even though there exist optimal steady state values for the reactions. With non-zero discount rates the criteria in our problems converge if the state level is reached. When evaluating the profits related to the steady state solutions we assume that the initial state coincides with the point of intersection of the steady state reaction curves and we compare the related steady state values of the net revenue flows.

We shall illustrate the game on the choice of policy variables in an example with zero discount rates. We get altogether nine different steady state Nash equilibria. The set of Nash point revenues defines the game on the choice of policy variables shown in Figure 1, where the entries are the steady state net revenue flows. Because our basic assumption was that perfect co-

operation cannot be guaranteed the Nash equilibrium solution is taken to be the desired solution. Here the Nash solution is the pair of policy variables h_1, h_2 , i.e. both countries use the harvest rate as their policy variable. Pair h_1, h_2 is also the closest point to the set of non-interior Pareto optimal solutions [6]. Hence, it may not be an accident that the resource negotiations are generally carried out in the terms of harvests rather than in the terms of stock level or fishing effort e.g. size of the fleet. The use of the effort level as a policy variable is not necessarily realistic because then the players are assumed to know the correct form of their opponent's production function $h(E)$. However, in this special case the Nash solution in the 2×2 subgame, where the effort levels are omitted, is the same as the solution of the complete 3×3 matrix game.

Finally there are some additional notes to be made. First, if the countries knew each others' performance criteria, then each country could compute the outcomes independently and they could be willing to negotiate among they generally desirable Pareto optimal solutions. Second, the inclusion of closed-loop strategies, which are not likely to be unique, would require a more complete analysis. In fact, it seems that this two-stage game could be embedded in a general closed-loop game where the strategies are allowed to be functions of stock level, harvest rate and fishing effort. Third, in the dynamic formulation of the present model, where the performance criteria are not known, there are different ways for the players to cheat each other [3]. In general, cheating can be a quite realistic policy alternative in fisheries management. Thus, efforts should be made in order to develop implementable and credible strategies which discourage cheating during the utilization of valuable marine resources (see e.g. [4,5,8-10]).

5 Conclusion

In this paper we have shown how a fairly simple resource management problem can result in an unexpectedly complicated dynamic game. The special characteristics of the dynamic game are due to the fact that we have a non-linear system model and that the players have the freedom to announce their decision using three alternative policy variables.

Clearly, our treatment of the game is an illustrative description of the problems than a complete solution. Many important game theoretic and fishery economic problems remain to be studied. The formulation of the present game as a general closed-loop game would be of immediate interest. Altogether this paper shows that there are essential problems in the management of divided international renewable resources, which need further modelling and analysis using the theories of static and dynamic games.

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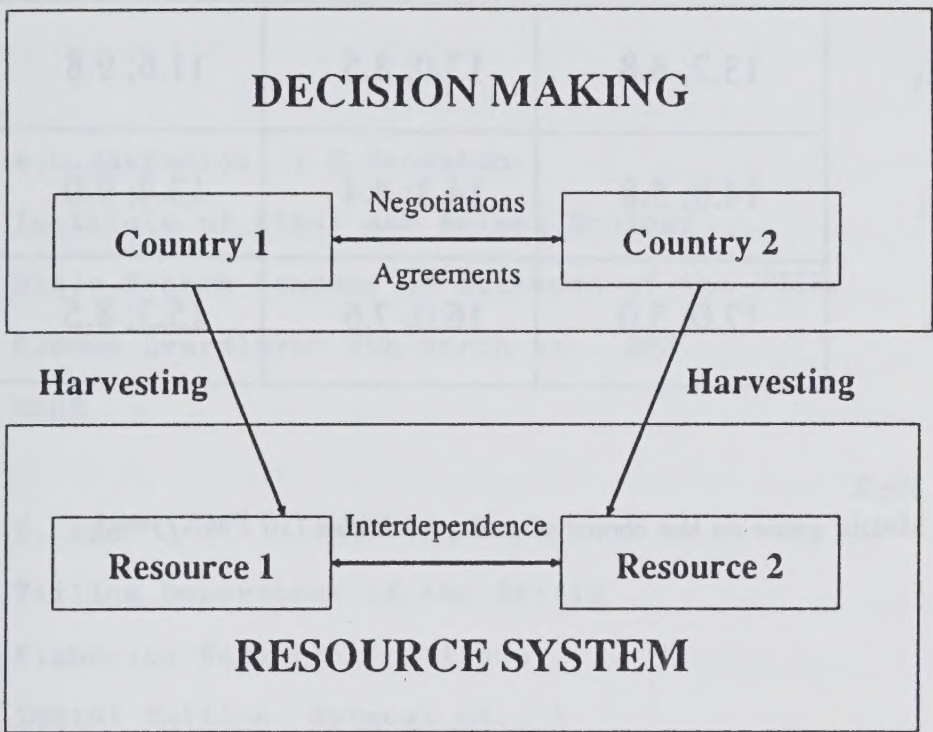


Fig. 1. A two-nation fishery problem

	X_2	E_2	h_2
X_1	13.2; 6.8	13.0; 8.5	11.6; 9.8
E_1	14.8; 5.8	14.3; 8.4	13.4; 9.0
h_1	17.0; 5.0	16.0; 7.6	15.3; 8.5

Fig.2.

Matrix game on the choice of policy variables (10 FMK/year)

THE MODEL OF SPRAT POPULATION DYNAMICS IN THE NORTHERN BALTIC

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Abstract A discrete time model of the Baltic sprat population dynamics is reported. The following dependence of recruitment on water salinity, temperature and sprat spawning stock abundance was used:

$$R_{t+2} = (a_0 + a_1 * V_t) * N_t / (1 + c * (N_t - N_{cr}))$$

where R_{T+2} is the recruitment in year $T+2$, N_T is the spawning stock abundance in year T , V_T is the index of suitability of abiotic conditions for sprat eggs development in year T , $c=0$ for $N_T \leq N_{cr}$, $c=\text{const} > 0$ for $N_T > N_{cr}$, c , a_0 , a_1 , N_{cr} are the parameters estimated.

It is shown that fluctuations in sprat abundance in the Northern Baltic are due to the periodical appearance of rich year-classes. A hypothesis is suggested and confirmed by the data on the North Baltic sprat population that successful survival of eggs is of decisive importance for the abundance of corresponding year-classes in a following year. It is shown by model simulations that even complete absence of fishery does not affect the general trend of sprat abundance dynamics. Thus, the optimal strategy for sprat fishery appears to be most intensive exploitation of a numerous year-class as soon as it reaches commercial size.

1. INTRODUCTION.

The dynamics of sprat in the Northern Baltic has been studied for more than a century. The body of data available at the present time is such, that their combined analysis and a forecast of abundance are hardly possible without developing of a model for the sprat population dynamics. In [1], we reported a general approach to the development of such a model. In this paper, we construct a simulation model for the sprat dynamics in the Northern Baltic.

Our results are based on experimental data on sprat fishing and analysis of over 100,000 sprats collected from experimental and commercial catches in the Northern Baltic during 1949-1987. Sprat spawning stock abundance and biomass in 1950-1987 were calculated by virtual population analysis (VPA) [4]. Oceanological data, such as mean values of temperature and salinity for standard horizons from the surface down to the halocline were obtained by decades over 1961-1985 at the standard station No.37 in the Baltic Sea.

2. MODEL

Consider in detail the model for the dynamics of the Baltic sprat. In this report, the model is used in its reduced version. The numerical analysis has been performed by the FORTRAN program given in the Appendix.

Fig. 1 shows the basic demographic processes timed with respect to each other for the Northern subpopulation of sprat. In this study, the following simplifying assumptions are made: migration is not taken into account; full description of the reproduction process is replaced by a simplified description of recruitment of one-year old individuals at the beginning of a year due to considerable difficulties in the description of survival at earlier stages. Fig. 2 presents the timing relationship between the demographic processes that are taken into consideration in this variant of the model.

The dynamics of sprat is described in the model by a system of difference equations:

$$X(T*L+h+1)=A(T*L+h)*X(T*L+h), \quad 0 \leq h < L \quad (1)$$

where $X(T*L+h)=(x_2(T*L+h), \dots, x_J(T*L+h))$ is the vector of the year-class numbers at time h of year T , L is the number of time steps in a year. We denote the number of sprats at the beginning of year T as N_T ,

$$N_T = \sum_{j=2}^J x_j(T*L)$$

Depending on the time within a year, for $t=T*L+h$ matrix A has the following form in accordance with Fig. 2:

$A=A_1$ for $0 \leq h < H_2$, $A=A_2$ for $H_2 \leq h < H_3$, $A=A_1$ for $H_3 \leq h < L-1$,

$$A=A_3 \text{ for } h=L-1, \quad (2)$$

where

$$A_1 = \begin{vmatrix} (1-m_2(t)-u_2(t)), & 0 & \dots & 0 \\ 0 & 1-m_3(t)-u_3(t), & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1-m_J(t)-u_J(t) \end{vmatrix}$$

$$A_2 = \begin{vmatrix} 1-m_2(t) & 0 & \dots & 0 \\ 0 & 1-m_3(t) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1-m_J(t) \end{vmatrix}$$

$$A_3 = \begin{vmatrix} E_2(t) & E_3(t) & \dots & E_{J-1}(t) & E_J(t) \\ 1-m_2(t)-u_2(t), & 0 & \dots & 0 & 0 \\ 0 & 1-m_3(t)-u_3(t), & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & 1-m_{J-1}(t)-u_{J-1}(t), & 1-m_J(t)-u_J(t) \end{vmatrix}$$

Here $m_j(t)$, $u_j(t)$ are the natural and fishing mortalities in year-class j over period of time $[t, t+1]$; $E_j(t)$ is the number of one-year old fishes per one

individual of class j . We assume below that $F_2(t) = \dots = F_j(t) = F(t)$. Hence,

$$F(t) = F_T = R_T + z/N_T \quad (3)$$

where R_T is the recruitment of one-year old individuals in year T .

To estimate $m_j(t)$ we make use of the natural mortality estimates per year ($q_j(T)$) accepted by the ICES [2]. We further assume that $m_j(t)$ depends only on T , so

$$m_j(T \cdot L + h) = 1 - (1 - q_j(T))^{1/L} \quad \text{for } 0 \leq h < L \quad (4)$$

The same assumption is made for $u_j(t)$:

$$u_j(T \cdot L + h) = 1 - (1 - s_j(T))^{1/(H_2 + L - H_3)} \quad \text{for } 0 \leq h < L \quad (5)$$

Here $s_j(T)$ is the fishing mortality per year T , as estimated by VPA. The values of $m_j(t)$, $u_j(t)$ per month calculated by (4) - (5) are given in Table 1.

This paper studies the annual dynamics of stock which is described by the vector of abundances of year-classes at the beginning of a year. This vector satisfies the equation

$$X((T+1) \cdot L) = B(T \cdot L) X(T \cdot L), \quad (6)$$

where $B = A_3 \cdot A_1^{L-H_3-1} \cdot A_2^{H_3-H_2} \cdot A_1^{H_2}$.

For simulation of the sprat population dynamics, of primary importance is adequate description of recruitment.

3. DEFINITION OF RECRUITMENT

The absolute value of recruitment calculated by VPA fluctuates with an amplitude of 10^4 : from $3.2 \cdot 10^6$ in 1985 to $5.6 \cdot 10^{10}$ in 1955. Fig. 3 shows a two-dimension distribution

of recruitment and stock for a period of 1950-1986. From the figure it follows that for any stock size both small and large recruitment is observed. This fact implies that recruitment depends not only on stock size but on other factors too. It would be natural to analyze the effects of other factors on $Fr = R_{t+2}/N_t$. Hereinafter we call this ratio "specific recruitment".

From 1950 to 1986 specific recruitment also fluctuated with an amplitude of 10^4 : from 4.0×10^{-3} in 1960 to 1.0×10^1 in 1955. We think that this fluctuation is caused by variations of the abiotic environment, especially, by changes in the conditions of sprat eggs development.

The sprat has pelagic eggs, therefore the basic condition for survival of these eggs should be staying in a layer of water favorable for development. Thickness and location of this layer depends on two factors. From above the layer is limited by a zone of turbulence through which eggs can float up to the surface and be damaged by waves. According to our data the turbulent zone extends down to a depth of 10 m from the surface. From beneath, the favorable layer is limited by a temperature threshold, which, in this study, is assumed to be about 6°C. It should be noted that the depth of this temperature threshold varies through changes during the spawning time, the pattern of variations being different for different years. Thus the thickness of the layer favorable for the development of eggs can vary both during the spawning time and from year to year.

There are several physiological mechanisms ensuring the swimming of fish eggs. Consider two of them: an extremely high water content of the yolk and the ingress of sea water in the perivitelline space at the time of fertilization. Both mechanisms act so that the density of eggs becomes close to the density of ambient water. In the sprat only the first of these mechanisms has been observed [5]. No adapting mechanisms bringing about changes in the density of eggs after spawning have been found in the sprat so far. Therefore we think that the density of eggs is adjusted during ovogenesis and does not change after spawning. Thus the eggs should swim at a depth where the density of water is equal to the density of eggs. For the observed ranges of changes in physical parameters the density of water above the halocline depends predominantly on its salinity. It can be easily shown that the effects of changes in temperature and the oxygen content on density of water can be neglected. The water salinity in the open part of the Northern Baltic changes with depth from about 6 to 8 promille, the vertical distribution of salinity changing with time.

The essence of our hypothesis is that the variability of the density of sprat eggs is small and is considerably lower than the variability of water salinity above the halocline. This should result in the fact that the majority of eggs will be distributed within a relatively narrow layer of water, and often this layer is beyond the limits of the layer favorable for their development. This hypothesis can

explain the rarity of sprat-rich year-classes: during 1950-1987 specific recruitment exceeds 1 only thrice i.e. in 1955, 1956 and 1967.

To predict recruitment by the distribution of salinity and the position of the 6°C isotherm it is necessary to know the distribution of density of sprat eggs. We assume that the density of eggs is normally distributed with a mean corresponding to the density of water, the salinity of which is equal to 7.39 promille, and standard deviation equal to a change in the density of water corresponding to a change in salinity by 0.02 promille.

The fraction of eggs spawned in a decade with a density such that they get in the favorable layer of water can be determined as follows:

$$P_i = G(d_1^i) - G(d_2^i) \quad (7)$$

where i is the number of a spawning decade, d_1 is the depth of 10 m, d_2 is the depth of the 6°C isotherm, $G(d)$ is the normal distribution function. Because of the lack of observation data we assume that the spawning intensity does not vary over the spawning period. In this case, the average value of P_i over spawning decades reflects the suitability of the abiotic conditions for sprat eggs development:

$$W = 1/K * \left(\sum_{i=1}^K P_i \right), \quad (8)$$

where K is the total number of spawning decades.

Hereinafter we use value $V = W * K$ in the formulas to denote the suitability of the abiotic conditions for sprat eggs

development. Based on the physical sense of index V , specific recruitment can be assumed to be directly dependent on this index. Apparently, this dependence can be approximated by a linear regression. The values of index V and specific recruitment into the second age-class (R_{t+2}/N_t) for 1961-1985 are presented in Table 2, and their combined distribution and regression line in Fig. 4. The latter shows that some of the points lie far from the regression line while two of them, i.e. for 1962 and 1965, are in great contradiction to our hypothesis. While looking for an explanation for this fact we noticed that in 1961-1966 the sprat stock was bigger than in 1967-1985 by an order of magnitude: the stock changed from $1.5 \cdot 10^{11}$ to $6.2 \cdot 10^{10}$ in 1961-1966 and from $6.6 \cdot 10^{10}$ to $4.3 \cdot 10^9$ in 1967-1985. We suggest that during years of high abundance the sprat population is controlled by some form of selfregulation mechanism exists and the specific recruitment is inversely proportional to the number of fishes. To improve approximation we introduced this dependence into the regression equation as follows:

$$R_{t+2}/N_t = (a_0 + a_1 \cdot V_t) / (1 + c \cdot (N_t - N_{cr})) \quad (9)$$

where a_0 , a_1 are the linear regression coefficients reflecting the dependence of specific recruitment on V_t in years of low abundance, N_{cr} is the critical abundance of stock above which the inverse dependence of the specific recruitment on the stock size makes itself prominent, c is

the proportionality coefficient ($c > 0$ for $N_t > N_{cr}$ and $c = 0$ for $N_t \leq N_{cr}$).

To estimate the values of the parameters we used the data obtained by the standard station No.37 in the Baltic Sea in 1966-1985.

We used NONLIN program from the SYSTAT system and the following regression equation was obtained:

$$R_{t+2} = (0.169 + 0.141 * V_t) * N_t / (1 + 0.471 * 10^{-9} * (N_t - 5.56 * 10^{10}))$$

$$\text{for } N_t > 5.56 * 10^{10},$$

$$R_{t+2} = (0.169 + 0.141 * V_t) * N_t \quad \text{for } N_t \leq 5.56 * 10^{10} \quad (10).$$

The accuracy of recruitment prediction depends not only on the validity of our hypothesis, but also on the fact how well the oceanological data used reflect the conditions in total spawning area. We think that to predict successfully sprat stock recruitment spatial regularities in changes in temperature and salinity of water should be taken into account. The model provides for this requirement and the corresponding blocks are present in the simulation program, though they are not used in this study.

4. RESULTS AND DISCUSSION

First of all, we checked the stock dynamics obtained by substituting the values of $q_j(T)$, $s_j(T)$, and R_t (Table 1) into the model for correspondence to the stock dynamics determined by the VPA. The initial condition for the simulation of stock dynamics was assumed to be the number of sprats in the age-groups determined by the VPA. In

agreement with expectations, the dynamics of stock determined by the VPA (Fig. 5) and the simulated dynamics obtained using recruitment and mortality values for each year determined by the VPA match totally. Such matching shows inherent consistency both of the model and of the VPA method and permits the estimates obtained by the VPA to be considered as a "control variant" to which other variants are compared below. In addition to the "control variant" (V1) we consider the following three variants.

V2. Relative recruitment is determined by the VPA; fishing mortality is assumed to be zero.

V3. Relative recruitment is determined by (10); fishing mortality is assumed to be equal to that determined by the VPA.

V4. Relative recruitment is determined by (10); fishing mortality is assumed to be zero.

In all these cases, we are interested in differences between the stock dynamics obtained in variants 2-4 and in the "control variant". Two criteria will be used for comparing dynamics curves. First, we compare population growth factors for different years, i.e. the values of $rt = N_{t+1}/N_t$. If curves a and b are synchronous, i.e. $N_t^a = N_t^b$ for all T , then $\delta T = rT^a / rT^b = 1$ for each year T . It should be noted without going into much detail, that when the curves are "nearly synchronous", the distribution of δ is close to normal with the mean equal to 1, the variance being small. The second criterion is based on the consideration of

relative difference between the two series, i.e. on the distribution of $\sigma = (N_{tr}^b - N_{tr}^a) / N_{tr}^a$. In this case, it also should be noted, that if the curves are close to each other in the absolute values of stock then σ is distributed normally with the mean equal to zero and a small variance.

First, compare V1 to V3, i.e. estimate suitability of (10) for describing the stock dynamics. Table 2 shows that both criteria reveal closeness of the curves, i.e. they are synchronous and there are no systematic differences over the years. Neither do variants 2 and 4 show any difference between them by the first criterion, though in these variants recruitment is estimated in a different manner, with fishing mortality being zero. Some difference in the shapes of the curves for V2 and V4 (Fig.6,7) is caused by differences in the population growth factor for 1971, 1972, 1986, 1987 due to the deviation of the recruitment values predicted by (10) from the actual ones. Variant 2 differs from variant 4 in the stock abundance at the probability level $p < 0.03$. The ratio of population growth factors in the variants without fishery and with it is 1.05-1.09, which is in agreement with the average annual fishing mortality (Table 1).

We think it to be an important fact that the absence of fishery in variants 2 and 4 does not result in an essentially different type of stock dynamics. Comparison of each of them with the corresponding variant with fishery (Fig. 6 and 7) clearly demonstrates that the only effect of

the absence of fishery is a change in the population growth factor over the entire period of 1969-1976 from 0.7 for V1 to 1.25 for V2. This difference corresponds to an increase in the population growth factor by 1.075 each year during this period. At the same time, all decreases of abundance during 1960s and in 1977-1986 appear also in variants without fishery. Both of these periods are characterized by a small value of relative recruitment, which is fairly well explained by unfavorable abiotic conditions in accordance with (10). In both variants, the absence of fishery results in an increase in the sprat abundance by a factor of 5-10 by 1986 as compared with the control variant, the general pattern of stock dynamics being unchanged. The stock decreases by 1980 and settles at a low level exceeding that observed in 1950-1956 by approximately a factor of 2-3. As a result, the amplitude of sprat abundance fluctuations over long periods of time exceeds the level of sprat abundance that would have been attained in 1980s without fishery by a factor of 10. The fact that the pattern of sprat population dynamics is qualitatively unchanged in the case of absence of fishery suggests that fishery cannot be the cause of fluctuations in the stock abundance in this species.

Fig. 8 presents the curves for recruitment and stock dynamics which clearly show that each sprat rich year-class was accompanied by an increase in stock abundance. Appearance of several rich year-classes during 1957-1961 (Table 1) results in an increase in sprat stock by

approximately a factor of 30 for the same period of time. Since the natural mortality of sprat, in our case, is substantially higher than the fishing mortality (Table 1), it would be natural to assume that it is the interaction between natural mortality and recruitment that determines the dynamics of sprat in the Northern Baltic, while fishery is an additional factor modifying stock dynamics rather than determining it. Thus, it is of principal importance that fishery is not involved in the decrease in sprat abundance in 1960s and 1970s. In this case, an optimal strategy of sprat fishery appears to be most intensive exploitation as soon as a sprat of a rich year-class reaches commercial size. Fishery limitations can be imposed only when the sprat abundance is low, in which case neither favorable conditions nor, possibly, high relative recruitment can lead to the recovery of stock. We cannot determine this level of "low abundance" based on the data available, since in this case one needs to know the relationship between the stock and the intensity of sprat fishery. Most probably, in the case of "low abundance" unprofitable sprat fishery makes the control of sprat fishery unnecessary at all.

Our conclusions are in contradiction with the existing view on the causes of decrease of the Baltic sprat abundance specifically, reported by F.Thurow [3]. The latter compares biomass production and catch in all units of the stock of the Baltic sprat in 1970-1980. The author claims that during this period of time, the total losses, including the catch

and losses due to other causes, exceeded sprat biomass production, while for the Northern stock unit (ICES Subdivisions 27, 29-32) the catch alone (less losses due to other causes), exceeded biomass production. This made the author to conclude that the cause of the fall in sprat abundance in 1970-1980 was overfishing. We cannot agree with this conclusion because analysis of the data available and the results of model simulations for 1950-1987, show that the Baltic sprat abundance fluctuates with a considerably higher amplitude over longer periods of time than 1970-1980 and fishery does not have any appreciable effect on these fluctuations. Of course, one cannot ignore that during years of low abundance, when the catch exceeds biomass production, fishery affects the sprat stock. However, it is evident that even complete of fishery for these years would not have led to a considerable increase in the stock by 1985-1986. It should be noted that the results obtained by F.Thurow [3] can be interpreted based on our conclusions: total losses in the Baltic sprat biomass during 1970-1980 exceeding biomass production, were caused by low recruitment and not by fishery.

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Table 1.

Sprat stock parameters in the Northern Baltic and values of the index V_T (see text for designation).

Year	natural mortality per month	fishing mortality per month	R_{T+2}/N_T	V_T
1950	0.2592	0.0128	0.0378	-
1951	0.2592	0.0185	0.4035	-
1952	0.2592	0.0230	0.1823	-
1953	0.2592	0.0174	0.0497	-
1954	0.2592	0.0203	0.0891	-
1955	0.1479	0.0389	10.1416	-
1956	0.1479	0.2123	6.4907	-
1957	0.1479	0.0258	0.8363	-
1958	0.1479	0.0204	0.2451	-
1959	0.1479	0.0166	0.4759	-
1960	0.1479	0.0211	0.0040	-
1961	0.1479	0.0219	0.0135	1.99
1962	0.1479	0.0262	0.0104	4.50
1963	0.1479	0.0338	0.0449	1.15
1964	0.1479	0.0463	0.1011	0.00
1965	0.1479	0.0503	0.0192	5.40
1966	0.1479	0.0555	0.0619	2.92
1967	0.1479	0.0557	1.0267	5.15
1968	0.1393	0.1270	0.3901	3.91
1969	0.1813	0.1002	0.3542	0.78
1970	0.1813	0.1173	0.2053	0.00
1971	0.1813	0.1095	0.1039	0.00
1972	0.2592	0.1203	0.4193	1.11
1973	0.2592	0.1916	0.1584	0.13
1974	0.2592	0.1477	0.0670	1.00
1975	0.2592	0.1456	0.7709	1.06
1976	0.2953	0.2250	0.3429	0.00
1977	0.2953	0.1230	0.0100	0.00
1978	0.2953	0.0855	0.0225	0.14
1979	0.2953	0.0888	0.0359	0.00
1980	0.2953	0.0988	0.2331	0.00
1981	0.2953	0.1349	0.0584	2.01
1982	0.2953	0.0841	0.5604	4.05
1983	0.2953	0.0959	0.1485	1.60
1984	0.2953	0.0870	0.2962	1.72
1985	0.2953	0.1247	0.0461	1.44
1986	0.2592	0.1138	0.3633	-
1987	0.2592	0.1655	-	-

Table 2.

Comparison of model variants:

1-3 - fishing mortalities from VPA

2-4 - no fishery

Compared variants	Index of matching					
	δ			σ		
	mean	variance	H: $\delta=1$	mean	variance	H: $\sigma=1$
1 - 3	1.088	0.116	$p > 0.20$	0.084	0.219	$p > 0.40$
2 - 4	1.048	0.056	$p > 0.30$	-0.245	0.117	$p < 0.01$

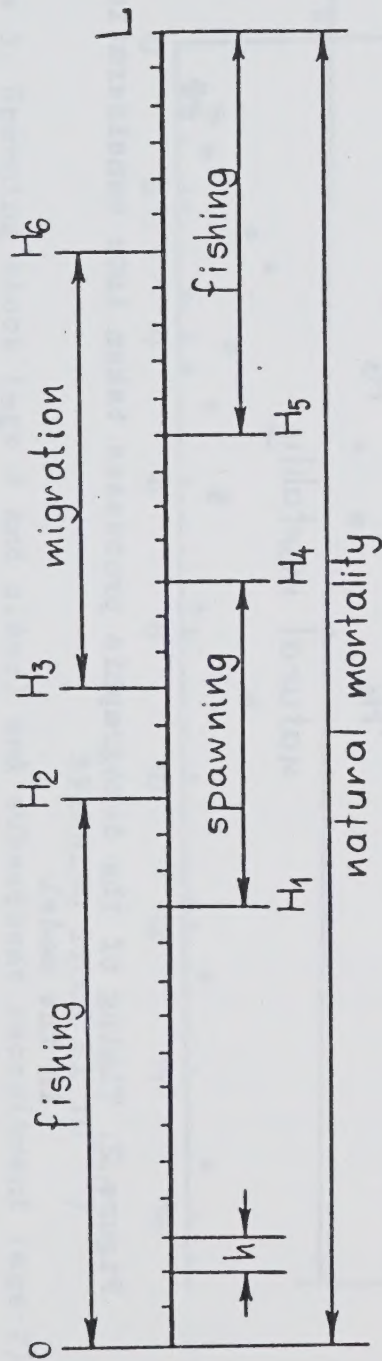


Figure 1. Timing of basic demographic processes in the northern subpopulation of Baltic sprat

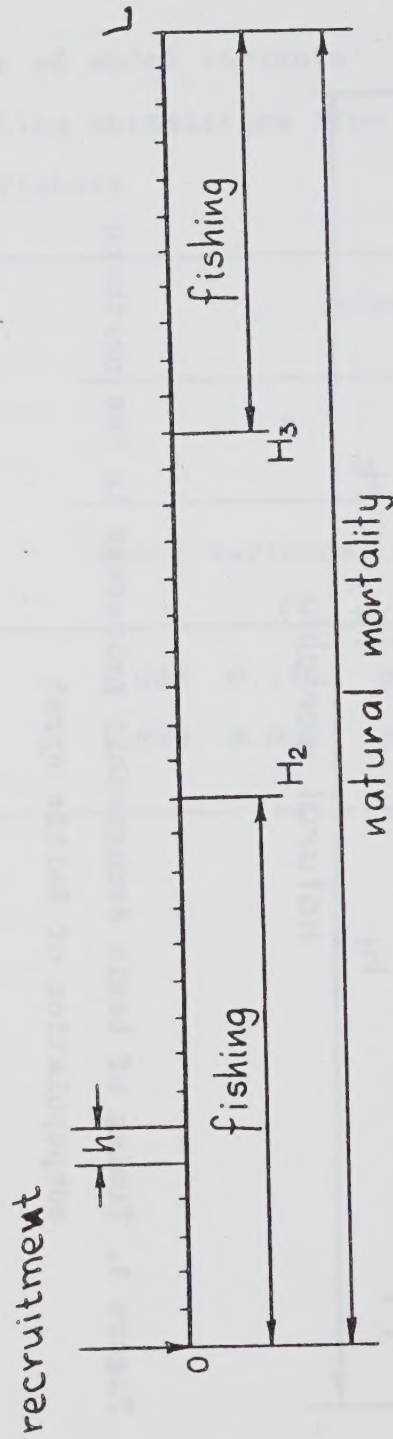
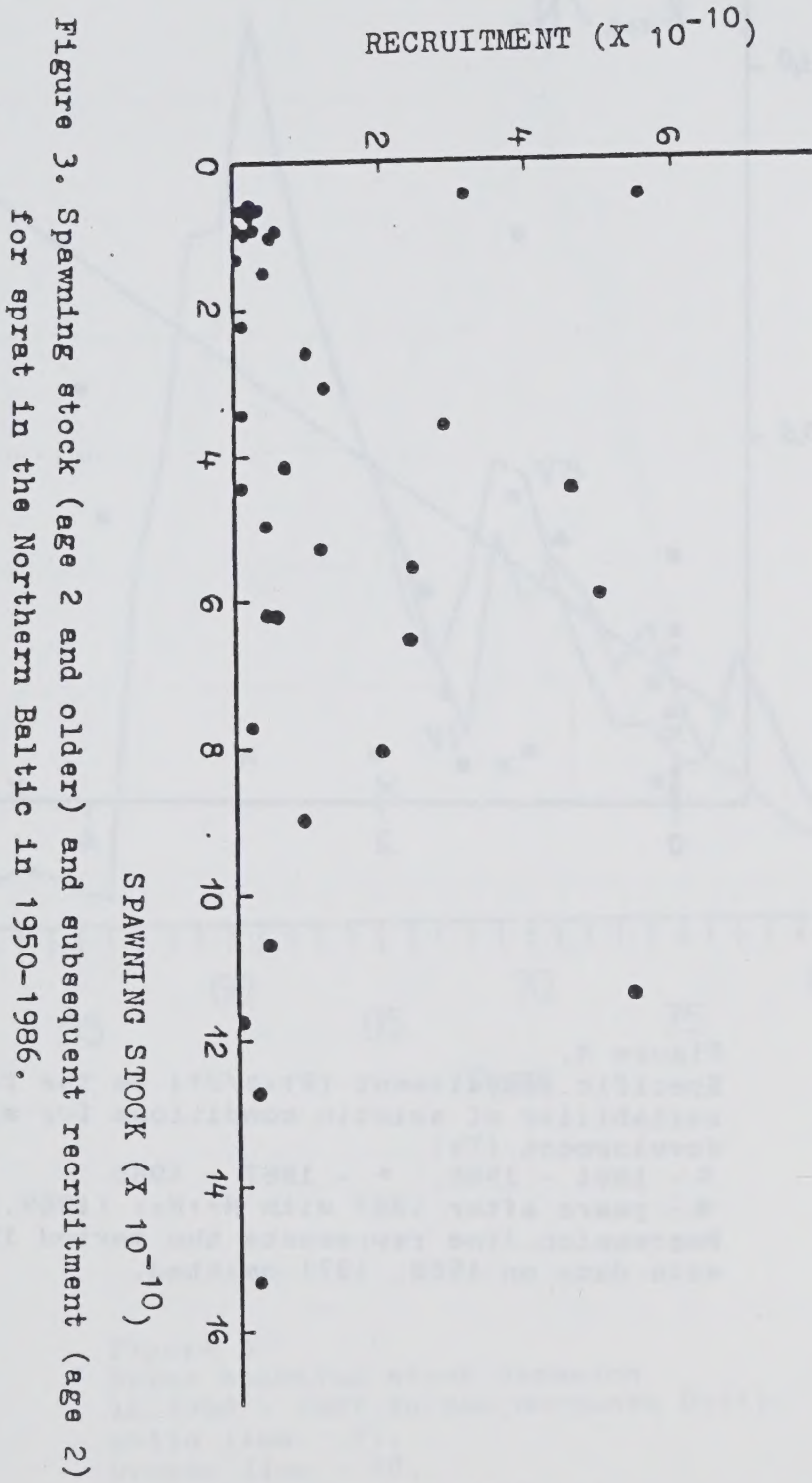


Figure 2. Timing of the demographic processes taken into consideration in the model



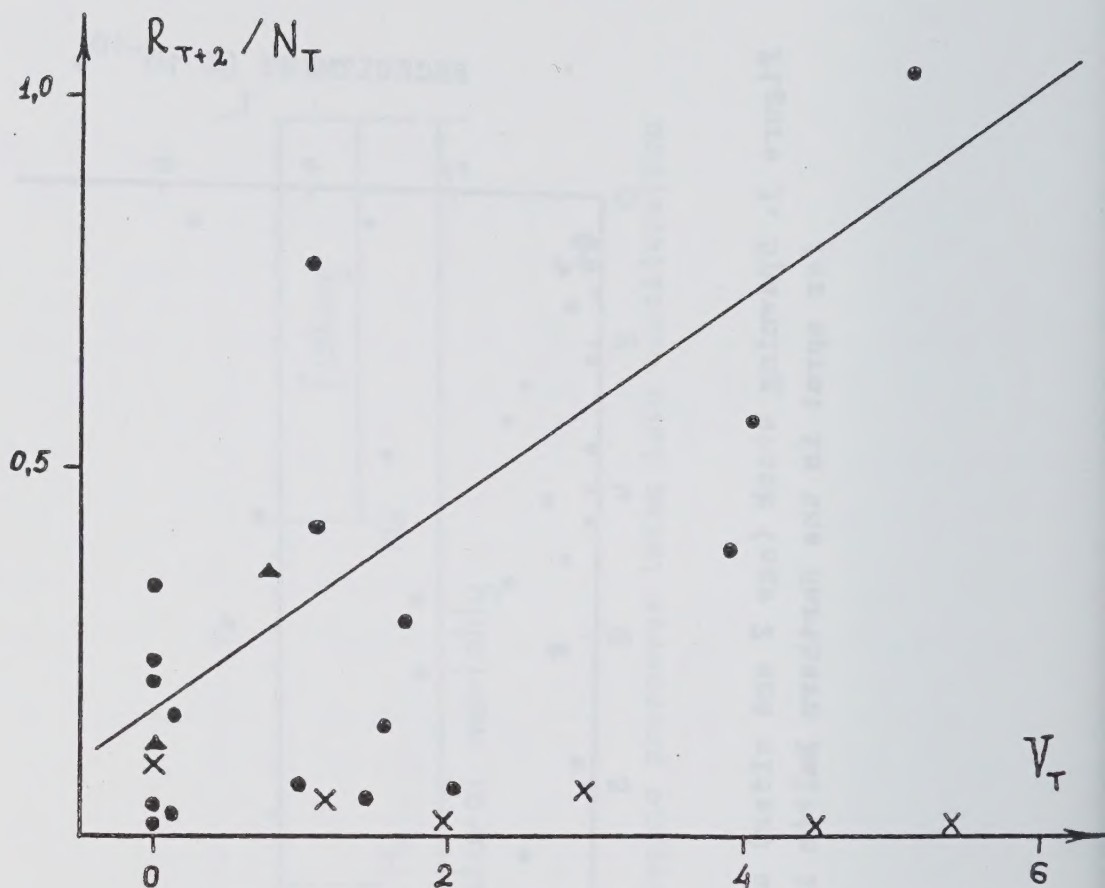


Figure 4.

Specific recruitment (R_{T+2}/N_T) as the function of suitability of abiotic conditions for sprat eggs development (V_T)

x - 1961 - 1966, • - 1967 - 1985

▲ - years after 1967 with $N_T > N_{cr}$ (1969, 1971)

Regression line represents the period 1967-1985 with data on 1969, 1971 omitted.

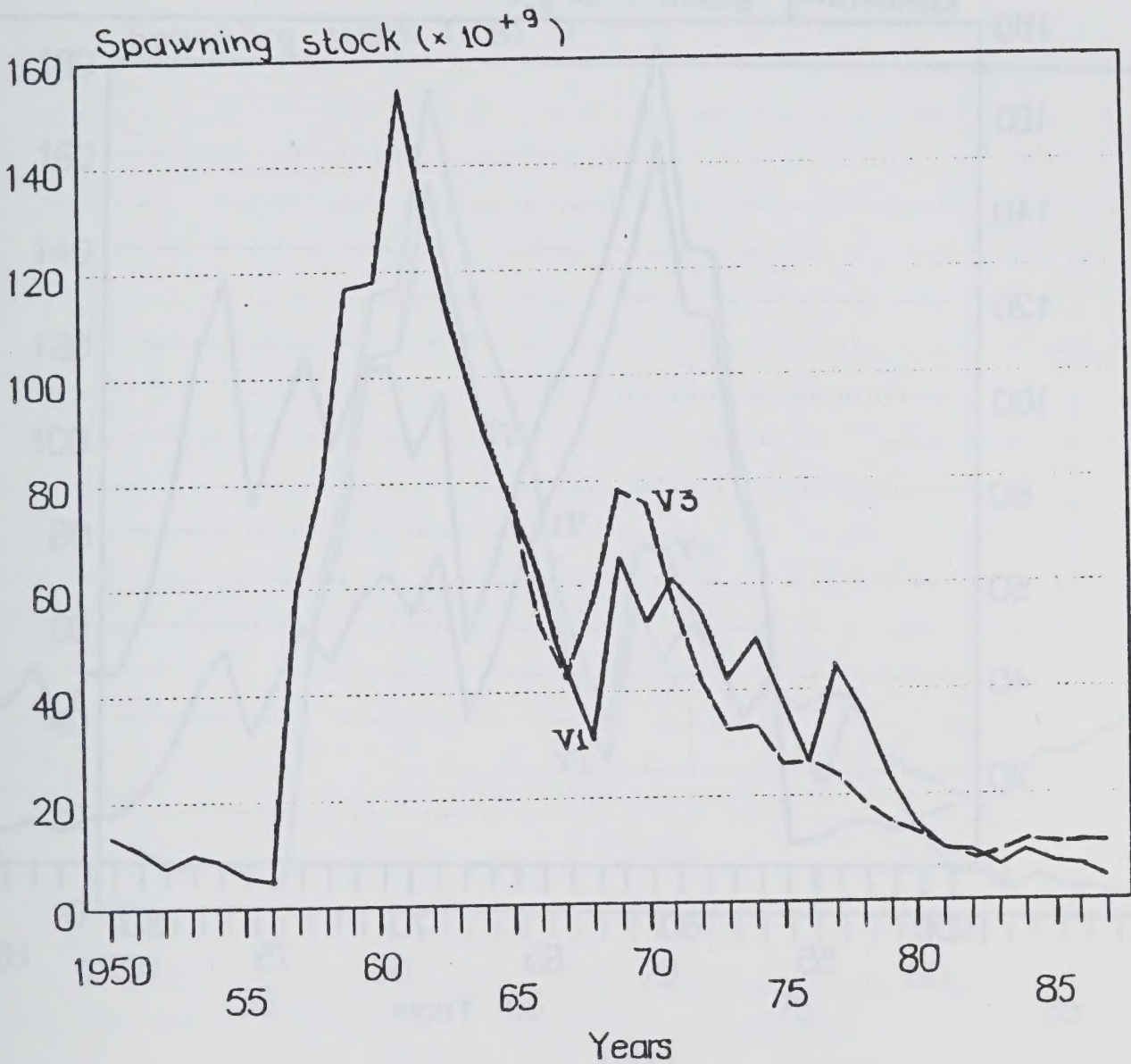


Figure 5.
 Sprat spawning stock dynamics
 in 1950 - 1987 in the Northern Baltic:
 solid line - V1,
 broken line - V3,
 (see text for explanations).

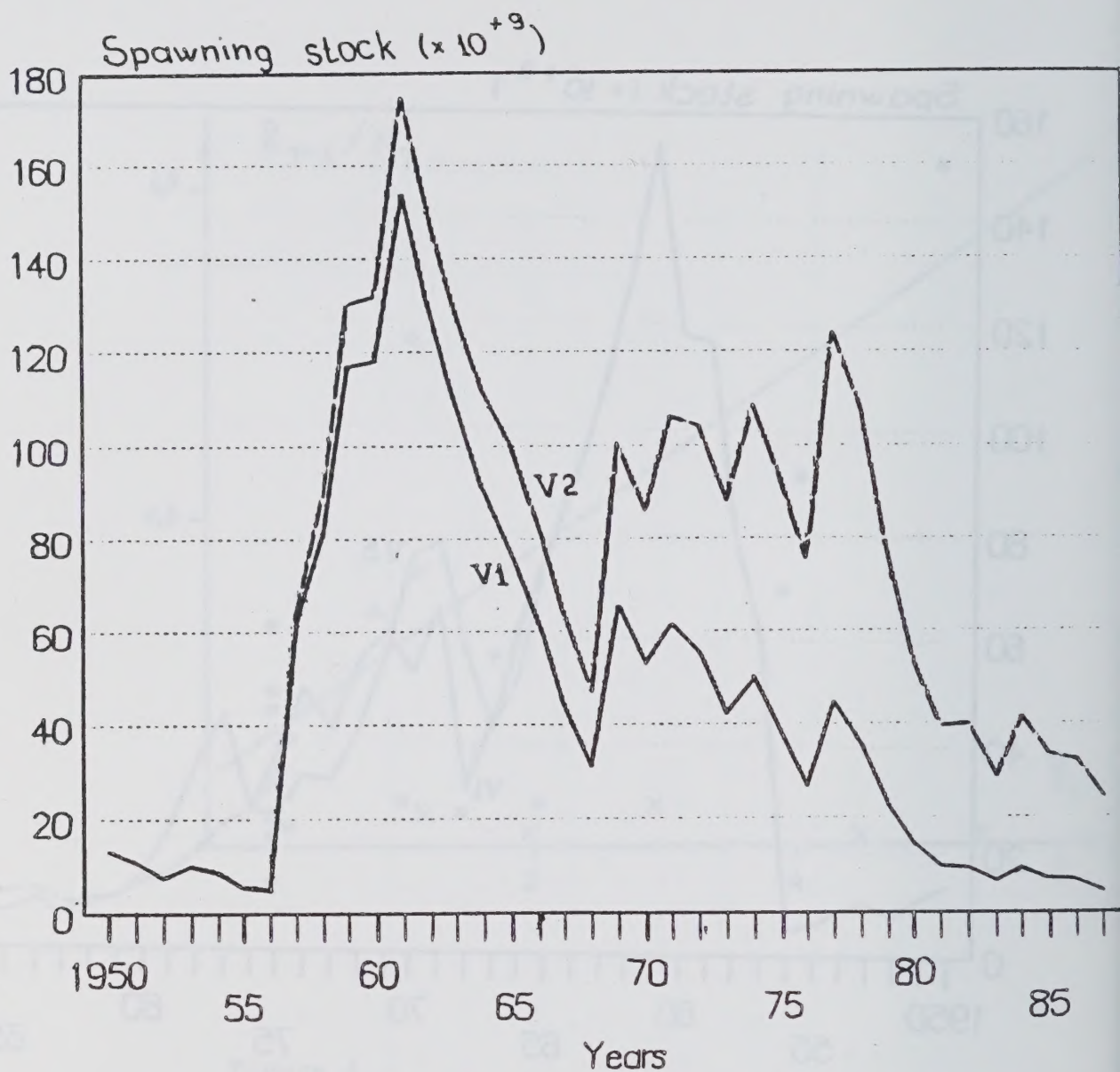


Figure 6.
 Sprat spawning stock dynamics
 in 1950 - 1987 in the Northern Baltic:
 solid line - V1,
 broken line - V2,
 (see text for explanations).

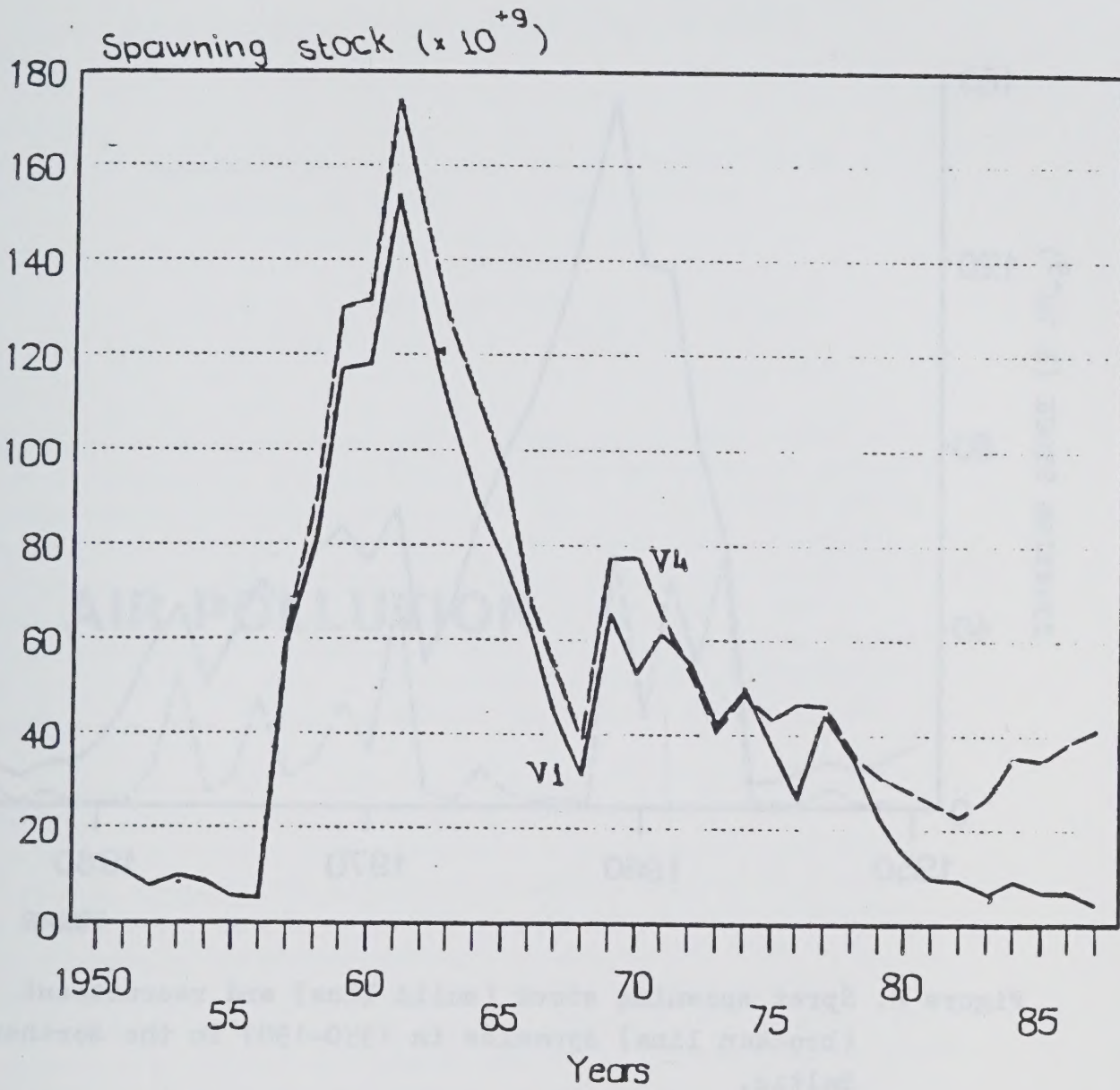


Figure 7.
 Sprat spawning stock dynamics
 in 1950 - 1987 in the Northern Baltic:
 solid line - V1,
 broken line - V4.
 (see text for explanations).

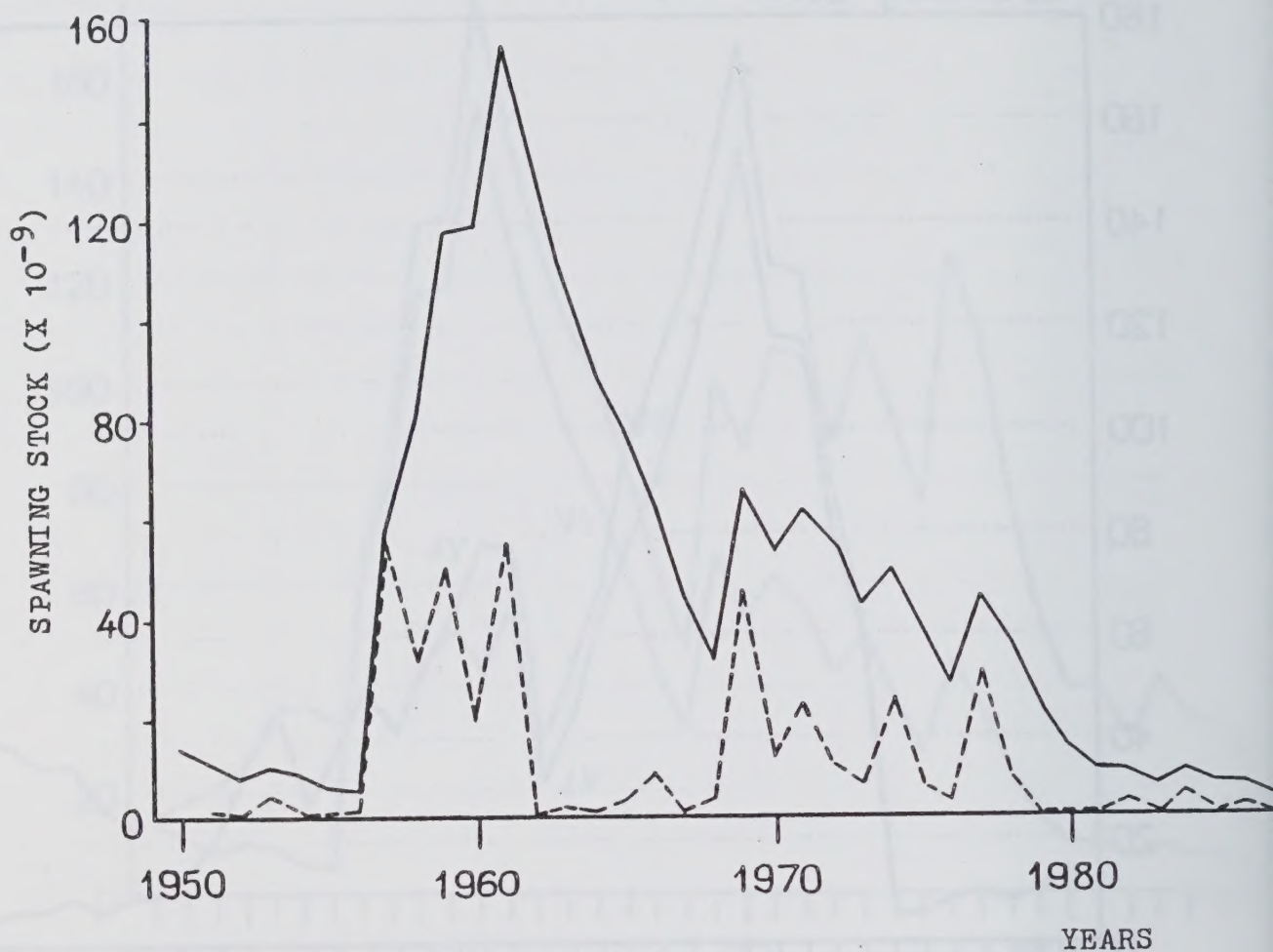


Figure 8. Sprat spawning stock (solid line) and recruitment (brocken line) dynamics in 1950-1987 in the Northern Baltic.

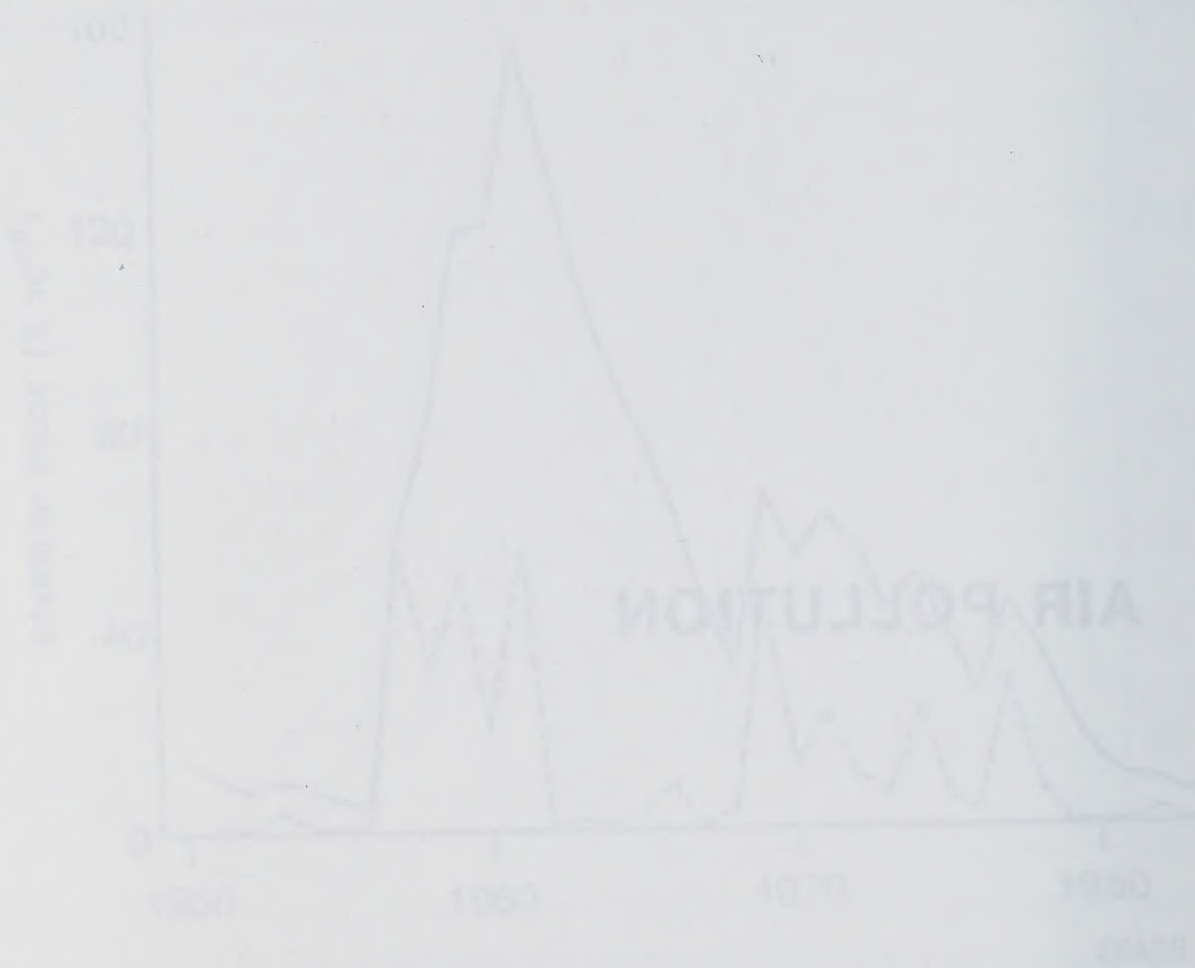


Figure 8. Spent space-time (solid line) and percentage (dashed line) of pollutants in 1950-1990 in the Northern Hemisphere.

DECISION SUPPORT SYSTEMS FOR AIR POLLUTION CONTROL

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Abstract Due to the simultaneous production of final energy and air pollutants, i.e. sulphur dioxide and nitrogen oxides in stationary energy conversion units, strategies for air pollution control affect directly the corresponding optimal future energy supply structure. Therefore, when implementing air pollution control strategies, it is necessary to analyse the real energy supply structure as well as alternative emission reduction measures for the countries or regions concerned. By doing this, it is possible to use energy-environmental models, e.g. EFOM, MARKAL or MESSAGE, as decision support systems.

In this report the methodological procedure for using the models as decision support systems is discussed. Moreover shiftings in the optimal future energy supply structure in European countries due to different strategies for air pollution control measures at stationary sources for the pollutants sulphur dioxide and nitrogen oxides are described using the extended Energy Flow Optimization Model EFOM, a model also in use at the Commission of the European Communities. By analysing the results obtained, optimal technical and economical measures will be derived. Using these results, an outlook is given on how to use this approach for determining optimal air pollution control strategies in the Baltic region.

The main results are based on research work the authors are performing for the Commission of the European Communities, Brussels, and the European Center for Air Pollution Control Measures, Karlsruhe.

1. INTRODUCTION

Among the variety of environmental problems discussed today air pollution has been regarded as being one of the most important ones. Apart from current discussions on the ozone problem and the greenhouse effect, acid rain especially has been in the center of interest in the last few years /1/. In this context, above all SO_2 and NO_x are the most important pollutants.

Air pollution is mainly caused by the conversion and use of energy. Energy and emissions are produced simultaneously. Therefore, environmental policy decisions aiming at the reduction of emissions affect the objective of energy policy to provide energy at the least cost and vice versa. That means, energy and environmental policy objectives and strategies cannot be developed separately, they are interdependent in nature. In general, the decision situation is characterised by a conflict between the objective of a low-cost energy supply and the objective to reduce emissions as much as possible.

Therefore, emission reduction strategies are required, which allow for the reduction of emissions in the most cost-efficient way, taking into account both, emission reduction measures and the energy supply structure of a country or region.

To achieve this goal, decision makers have to give answers e.g. to the following questions:

- What environmental regulations should we establish?
- How can we achieve the desired emission reduction in an efficient way, i.e.
 - by which technology options?
 - to which degree/efficiency?
 - with which admissible secondary negative side-effects (e.g. waste)?
- What will be the impact of pollution control on the energy supply system, e.g.
 - what additional costs will result?
 - what is the impact on the future emission level?
 - which shifts in the optimal mix of energy conversion technologies will result?

or to summarize

Which level of emissions are we willing to accept and which energy system option will comply with these requirements?

To answer these questions, energy and environment models, which take into account the nature of the above mentioned decision problem by allowing for the simultaneous consideration of energy and environment, can be applied as decision support tools.

In the past, several energy models, e.g. MARKAL, MESSAGE and EFOM, were developed aiming at the analysis of the energy supply system and the provision of a decision basis for energy policies /5, 12/. In order to be able to take into account the environmental aspects of energy supply as well, several of these energy models have been extended by environmental modules, allowing for an adequate modelling of the emission characteristics of energy conversion processes, applicable emission reduction technologies and environmental regulations. With the help of these models emission reduction strategies can be developed by decision makers, which are optimal with respect to a pre-defined objective (e.g. minimization of energy costs or minimization of emissions). Moreover, the application of such models allows for the performance of trade-off analyses of different objectives, e.g. cost of energy vs. emission reduction. With the help of such trade-off analyses the above mentioned interdependencies between environmental and energy policy goals can be made transparent.

In this paper the methodology for using such models as decision support systems is discussed. The analysis is based on current research projects at the Institute for Industrial Production (IIP) inter alia for the Commission of the European Communities, Brussels and the European Center for Air Pollution Control Measures, Karlsruhe. In these projects emission reduction and energy supply strategies are being developed for countries of the European Community /3, 11/. Similar projects are being carried out for Turkey and the Caribbean region at the IIP /6, 9/. Furthermore, an outlook is given on how to use this approach for the development of optimal air pollution control strategies in the Baltic region.

2. METHODOLOGICAL TOOL

A decision support model for energy and environmental analyses is the EFOM Energy Flow Optimization Model /12/. This model, originally developed as a pure energy model, has been extended by an environmental module at the IIP /3, 11/.

EFOM is a linear dynamic optimization model. The whole energy chain starting from the primary energy supply (e.g. coal, oil and gas sector) passing through the intermediate sectors (e.g. electricity supply) and ending in the demand sectors (industry, households, transportation, etc.) is represented by linear equations. Figure 1 shows the structure of the model. The model is organized in a modular way with each module or sub-system containing a set of alternative energy conversion technologies.

The technologies are represented by conversion efficiency, installed capacity, investment, cost, etc.

The objective of the linear programme is the minimization of the cumulated annual costs (present value) for the time horizon (1980 - 2010). However, it is also possible to define other objective functions, e.g the minimization of emissions.

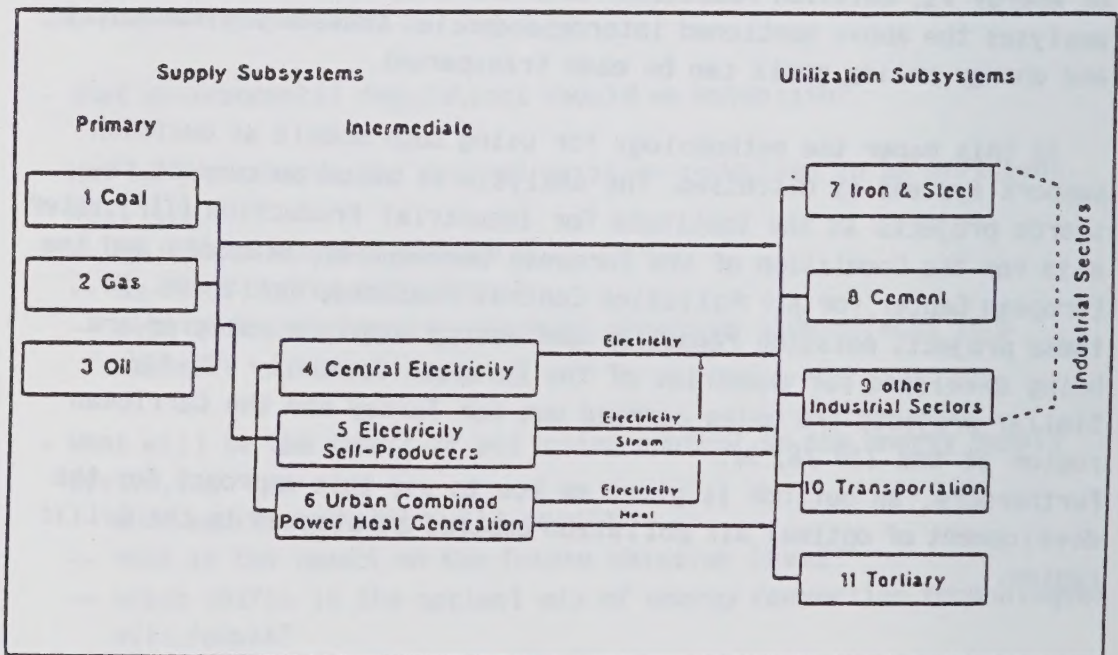


Fig. 1: Modular structure of EFOM /11/

The outcome of the model application is the optimal resource and technology mix to meet the exogenously determined energy demand with respect to the pre-defined objective criterion.

The EFOM energy model has been extended by an environmental module at the IIP aiming at the representation of the emission properties of the energy supply structure of a country or region, environmental regulations and technical options for the reduction of emissions. For this purpose, the emission characteristics of the use of different fuels (represented e.g. by its sulphur contents) in different energy conversion processes are represented by means of emission factors resulting in a representation of the emission flows in the energy system. For each energy conversion technology the possibility to reduce emissions is provided by assigning several emission control measures to each energy conversion technology (see Figure 2). These are for example dry limestone injection, the spray dryer process and the wet limestone process for SO_2 reduction and combustion modification measures and SCR process for NO_x reduction. Furthermore, environmental regulations are represented by additional constraints in the model.

The representation of the energy supply structure of a specific country or region in the model is based on the technical, economical and environmental analysis of the available energy conversion and emission reduction technologies /11/. Considering the outcome of this analysis, energy conversion technologies are aggregated e.g. according to their environmental properties. Furthermore, feasible future energy conversion and emission reduction technologies are selected. Possible future high-efficient, low-emission technologies are e.g. fluidized bed combustion or combined cycle processes for electricity production.

The application of the model as a decision support for the development of "optimal" emission reduction strategies can be characterized as follows:

Different emission control strategies are defined by means of scenario technique, i.e. each emission control strategy is represented by a scenario. By the application of the decision support model a least-cost mix of energy conversion and emission reduction technologies is obtained for each scenario or emission control strategy respectively. By the analysis of the resulting shifts in the energy supply structure and the resulting additional costs of emission control, the consequences of each emission control strategy can be identified and must be further evaluated in order to serve as a basis for environmental policy decisions.

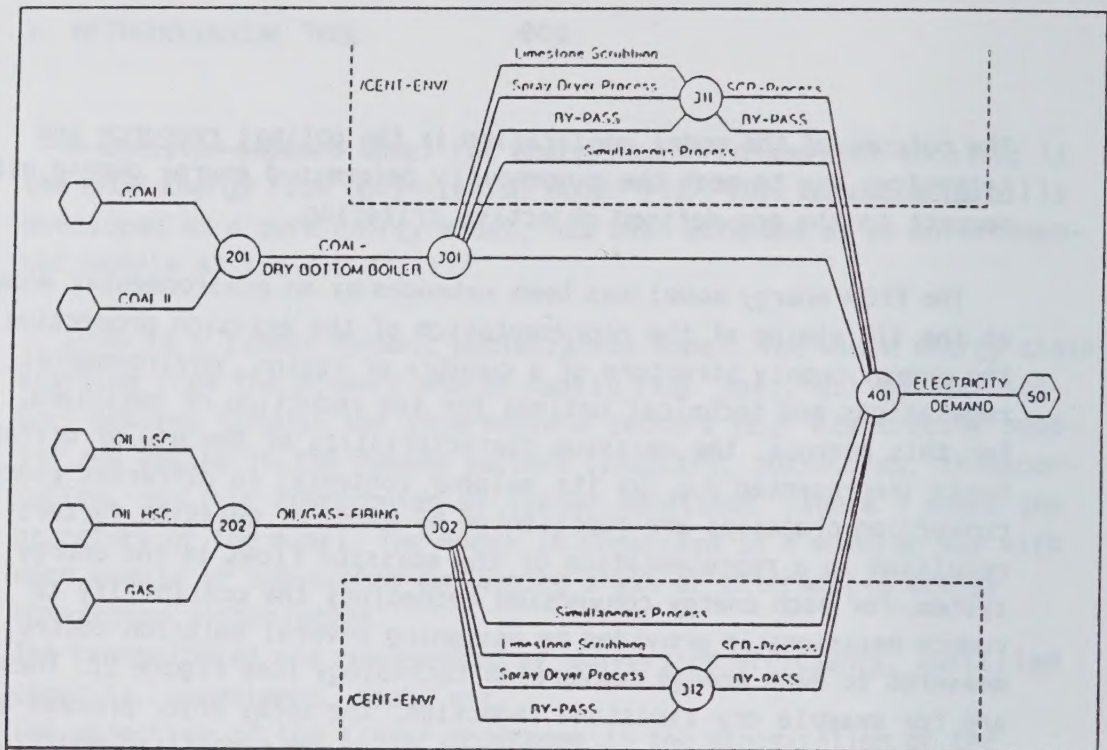


Fig. 2: Environmental module /11/

The scenarios defined in the current research study are:

- The "Legal Case", representing the current valid emission regulations of each country in the EC. For the Federal Republic of Germany these are e.g. the "Großfeuerungsanlagen-Verordnung" /7/ and the "Technische Anleitung Luft 1986" /8/, where plant specific emission standards for large and middle scale firings are defined.
- The "CEC-Case", representing the present discussions about an EC-wide directive for the reduction of SO_2 and NO_x for large combustion plants /2/.
- The "Cost-effectiveness Cases" in which a 30 %, 50 % and 70 % reduction of a country's overall SO_2 and NO_x emissions as in 1980 is required by 2000.

These scenarios can be interpreted as the representation of a nation-wide "bubble-policy" aiming at the achievement of a certain global emissions level in a cost-efficient way by allowing for an

optimal allocation of emission reduction measures in the whole energy sector.

The results of these scenarios can be used for trade-off analyses since cost vs. emission reduction functions are obtained showing the additional energy costs for different levels of emission reduction ("national cost functions").

- The results of all the scenarios are compared with the reference scenario, the so-called "Doing-Nothing-Case" where it is assumed that there are no additional environmental restrictions after 1980.

The results of these various scenarios can be used as a basis for the decision on the emission level, which will be regarded as acceptable for the future. In theory, the "optimal" emission reduction level is achieved by comparing the emission reduction costs of a country as represented by the national cost function, which is for instance obtained by the "Cost-Effectiveness" scenarios with the benefits of emission reduction, which result from the reduction or avoidance of emission induced social costs and which can be represented by a national or regional utility function. However, it is well-known that the construction of such utility functions gives rise to several methodological and practical problems, such as the quantification of the relation between causes and effects of air pollution or the measurement of utility or welfare.

Although cost-benefit analysis is beyond the scope of the research project, valuable statements can also be derived by analysing the cost functions by applying evaluation methods, which have been developed by decision theory.

In the following, some of the results of the application of the described approach for the Federal Republic of Germany will be discussed.

3. SOME RESULTS OF THE CEC-STUDY: THE FEDERAL REPUBLIC OF GERMANY AS AN EXAMPLE CASE

The SO_2 and NO_x emission reduction, which results from the actual legal situation ("Legal Case") in the Federal Republic of Germany is shown in Figures 3 and 4.

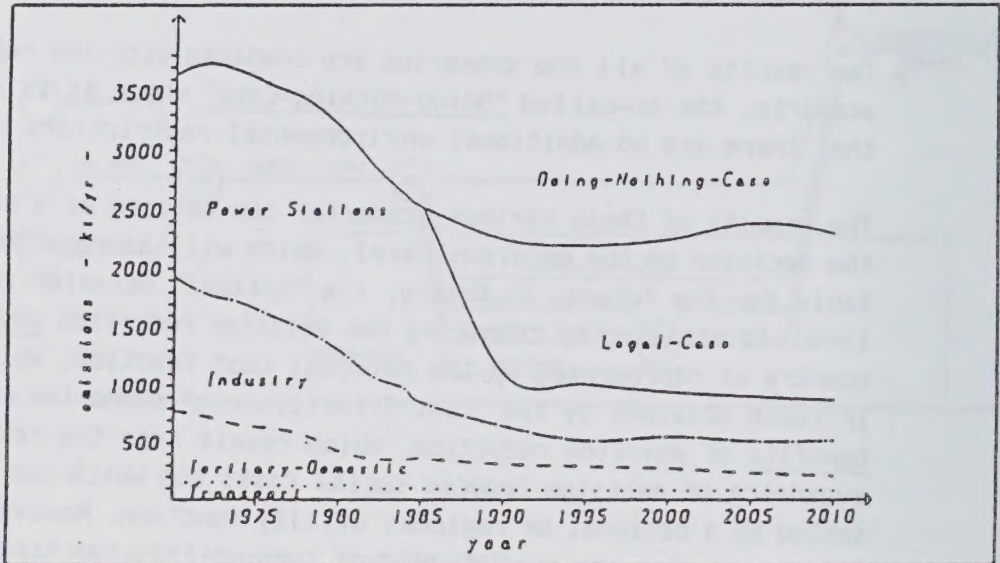


Fig. 3: Development of SO_2 -emissions /11/

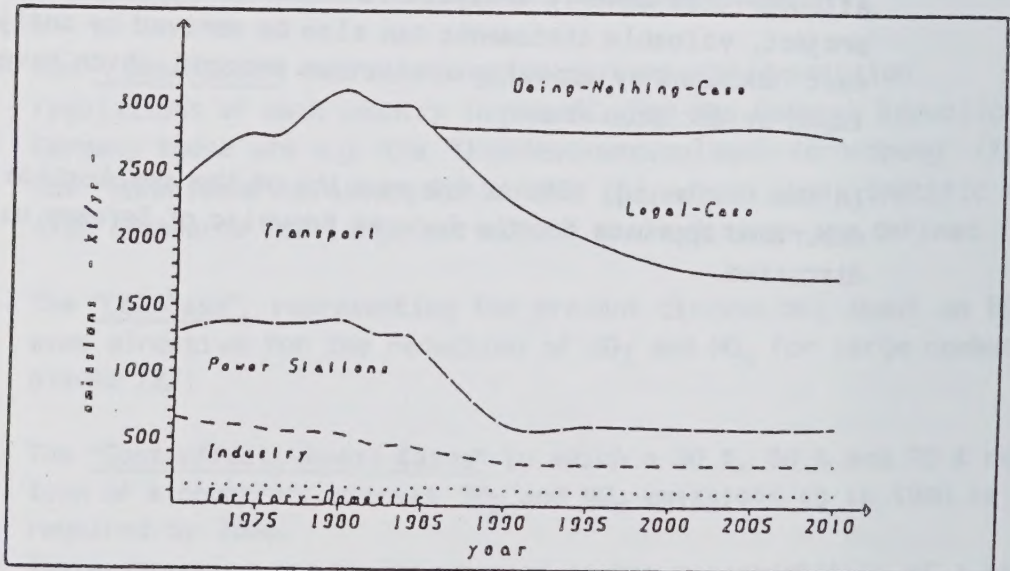


Fig. 4: Development of NO_x -emissions /11/

Figure 3 shows that the SO_2 emissions will be reduced effectively, i. e. by more than 70 % by 1995 compared with the 1980 level, resulting partly from the installation of flue gas desulfurization facilities, fuel switching in public utility and industrial power plants and the substitution of conventional power plants by new "clean coal technologies" like fluidized bed combustion or combined cycle systems.

The NO_x reduction according to the "Legal Case" will not be as effective as in the case of SO_2 (Fig. 4). This is mainly due to the fact that the reduction in the transportation sector, which is (contrary to SO_2) the biggest NO_x polluter, is expected to be less than 20 %. The NO_x reduction in the power plants will be nearly 67 % by 1995. Total NO_x emissions will be reduced by only 36 % by 1995 compared with the 1980 level.

The effects of an increasing stringency of environmental restrictions on the "optimal" energy supply structure and the associated costs can be analysed in the "Cost-effectiveness" cases:

The 30 % reduction of SO_2 is mainly achieved by fuel switching, i.e. replacement of fossil fired power plants by nuclear power and increased use of natural gas. However, a 30 % reduction of SO_2 is also achieved in the "Doing-Nothing-Case". That means that fuel switching is advantageous not only for environmental reasons but also to save costs.

This example shows that the objectives, reduction of emissions and reduction of energy costs, are not contradictory in all cases.

The increase in legal requirements (50 % and 70 % reduction) will result in the installation of emission reduction equipment (e.g. flue gas desulfurization plants, low- NO_x burners and SCR plants in public and industrial power plants or 3-way-catalysts in cars), intensified fuel switching (in favour of nuclear power and natural gas) and the replacement of conventional power plants by new "clean coal technologies" like combined cycle power plants or fluidized bed combustion. However, a 70 % reduction of NO_x is not feasible. This is mainly due to inflexibilities in the transportation sector.

As a result of the "cost-effectiveness" studies a national cost function or cost vs. emission reduction trade-off function is obtained (see Figure 5).

Figure 5 shows especially that a reduction of SO_2 and NO_x of more than 50 % will result in a steep increase of costs (defined as the present value of the cumulative additional expenses for emission reduction). As mentioned above, a trade-off function of this kind can be a

valuable instrument for the definition of an emission reduction strategy by making transparent the consequence of environmental protection on energy supply costs.

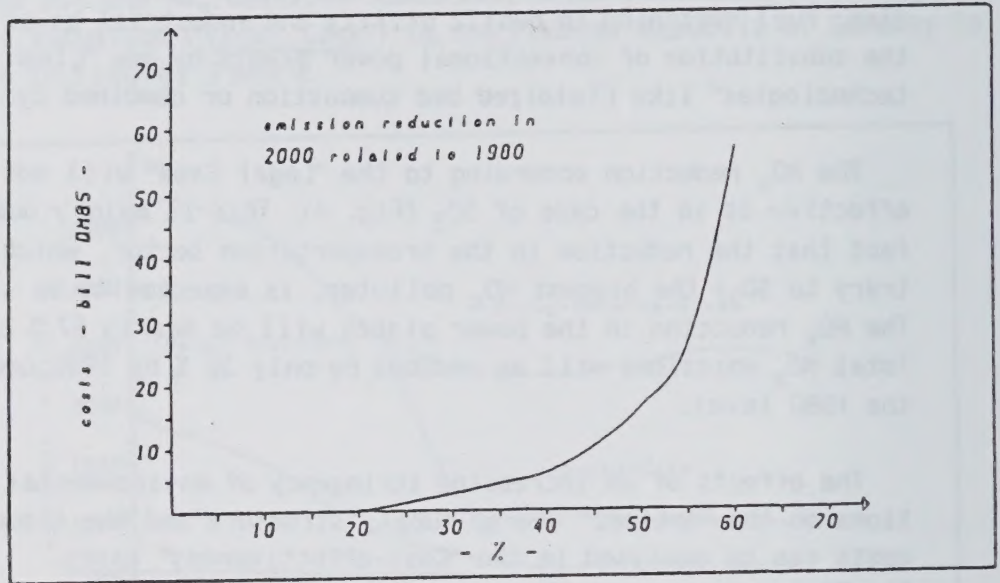


Fig. 5: Simultaneous SO_2 - and NO_x -reduction versus costs

As a general conclusion, it can be maintained that a reduction of emissions will in general result in a combination of fuel switching, switching to improved, high-efficient, low emission technologies and the installation of emission reduction technologies.

4. APPLICATION FOR COUNTRIES OF THE BALTIC REGION

The EFOM energy and environment model has proved to be a flexible instrument for energy and environment studies in various countries. Nevertheless, it must be pointed out that an application of the model to a certain region like the Baltic region requires an adaption of the model structure according to the energy supply structure specific to the region. This is due to the fact that different energy systems imply different environmental problems.

The adaption must be based upon a technical and economical analysis of the energy supply system of the region as well as the consideration of relevant economic and political issues. This analysis will be the basis for the aggregation of energy conversion technologies in the model and the selection of appropriate future energy conversion and emission reduction technologies.

Some examples from the Baltic region may illustrate this: According to its natural resource endowment, the Polish energy supply system is mainly based upon the use of hard coal in power plants, industry and households. The consequences are relatively higher SO₂ emissions per unit of total primary energy consumption (1985: 29,6 kt /4/) than e.g. in countries like Sweden (7,1 kt) with a different energy supply structure (lower share of fossil energy) and stricter environmental regulations /4/. Therefore, to adequately consider the environmental consequences of the energy production of the country in the model, it would be advisable to represent coal technologies more accurately and in a more disaggregated manner than in countries like Sweden with a much lower specific consumption of hard coal. This holds e.g. for hard coal fired heating systems in households which are widespread in Poland but of practically no importance in countries like Sweden or declining importance in the Federal Republic of Germany. Other examples are future "clean coal technologies" like the different types of integrated gasification combined cycle systems, fired with hard or brown coal.

Similar aspects apply to the situation in the German Democratic Republic. Due to its important share in the primary energy consumption the use of domestic brown coal and the well-known associated environmental consequences will be of major interest in energy-environmental studies.

Therefore, it would be sensible, for example, to distinguish several types of brown coals with regard to environmental properties, e.g.

according to their sulfur content.

Apart from an appropriate representation of the energy supply structure of a region in the model, economic and political restrictions or preferences must be considered in order to obtain a realistic representation of the energy sector.

This implies e.g. the consideration of middle-term power plant expansion programmes, of preferences like the Swedish memorandum on the use of nuclear energy, of import restrictions, of long-term contracts like gas or coal contracts, etc.

Furthermore, especially for "Legal-Case" studies, the actual environmental legislation must be represented. However, up to now no generally valid emission standards have been enforced for instance in Poland, the German Democratic Republic or the USSR.

By considering all the characteristics specific to particular regions, the EFOM model can be applied in the Baltic region analogously to the countries of the EC for the development of emission reduction strategies. Strategies can be developed for each country separately or for a region as a whole.

5. CONCLUSIONS

In this report the application potential of energy-environmental models has been described by using results of energy-environment studies for countries of the European Community, especially the Federal Republic of Germany.

The methodology for using such models for the development of emission reduction strategies for the Baltic region has been discussed.

By using energy and environment models, it is possible to determine an optimal mix of energy conversion technologies and fuels as well as an optimal allocation of emission reduction measures.

By using scenario techniques several "optimal" emission reduction strategies can be compared resulting e.g. in national or regional cost vs. emission reduction functions. These functions can be a valuable tool for environmental policy decisions.

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A COMPREHENSIVE ASSESSMENT OF THE AIR POLLUTION
LEVEL (FOR THE PURPOSES OF ENVIRONMENTAL PLANNING)

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Abstract The paper discusses methodological problems of integral assessment of atmospheric air pollution. A novel approach to generalized, comprehensive assessment of pollution considering the concept of different hazardousness of pollutants to the human organism in case of equal violations of standards is introduced. A technique for finding a synthetic comprehensive index, the so-called air pollution index, and possibilities of its practical application by environmental management agencies are described.

1. INTRODUCTION

Planning and design offices, monitoring systems and environmental protection agencies often need generalized comparable estimates of the air pollution of some territorial unit (city, city district, industrial centre). In such cases it is advisable to use composite indices (e.g. SO_2 , CO , NO_x , etc. content). Such relative synthetic indices give a good possibility to compare different territories and simultaneously follow air quality changes in time [1, 2].

In order to regulate air pollution so that pollution standards were not surpassed counter-activities must be planned on regional (republican), city and often even city district level. Though the combination of sectoral and territorial principles has been widely discussed in theory (see e.g. [3, 4]), in practice next to nothing has been done in this field. Besides numerous other reasons, lack of appropriate

indices oriented toward the final results, i.e. air quality should be mentioned. The majority of plan targets in the field of environmental protection used since 1974 do not in essence characterize the state of the components of environment, rather, they are indices directed toward achieving a normative state. In general, the plan targets are oriented toward reducing air pollution, however, we lack comprehensive estimates characterizing the change (improvement) in air quality, i.e. indices showing the efficiency of the measures taken, the so-called feed-back indices.

It should be stressed that the final objective of air protection expenditures is man, his health and comfort. If we formulate this principle strictly, we could say that by taking respective measures, at least air quality corresponding to sanitary-hygienic standards for all major pollutants must be achieved.

2. TRADITIONAL WAYS OF ESTIMATING AIR POLLUTION

Environmental pollution in general as well as air pollution is characterized by the higher than general formation or presence and persistence over some time of vibration, radiation and substances harmful to human beings, flora and fauna. Such radiation, vibration or substances may be common components of environment. As the treatment of air pollution in the present paper is confined to various substances and chemical compounds, we shall define air pollution in this context.

Air is regarded as polluted if it contains higher than the permissible quantity of substances that are not basic components of atmospheric air, or if the content of traditional components is too high (or, in exceptional cases, too low).

The level of air pollution is closely connected with meteorological conditions: temperature, humidity, direction and force of prevailing winds, etc. As a result of the diffusion, transformation and transfer of pollutants a certain concentration

of them in the air or the so-called immission is formed. The most widely used unit of immission is mg/m in the Soviet Union. The generally known principle underlying air pollution standards in our land is the requirement that permissible immission of pollutants must not bring about direct or indirect harm to human beings, reduce their ability to work and worsen their health during their total life-span. The level of air pollution is assessed by comparing the actual immissions with the sanitary-hygienic standards set for the given pollutants, i.e. its maximum permissible concentration (MPC). Immissions higher than the MPC are regarded as not permissible. MPCs should help avoid such air pollution that may cause a reflectory counter-reaction (e.g. changes due to damage to smelling and irritation of mucuous membrane) in case of short-term exposure.

In the following long-term standards - maximum permissible average daily concentrations are considered only. Maximum permissible average daily concentrations must guarantee that no physiological changes are caused in the organism due to long-term exposure to the air.

The above-described so-called classical air pollution assessment method allows us to decide whether the air is polluted by some pollutant by comparing data with standards. A serious drawback of this method is that though the concentration of separate pollutants is estimated, there is no aggregate index considering simultaneously all pollutants. What can we say about air pollution in general if the immission of some pollutants is considerably higher than the respective standards while the immissions of the others are below their MPCs? In practice we have been facing this problem for a long time. The use of composite indices is indispensable since usually man is exposed simultaneously to several pollutants whose hazardousness to living organisms is different in case of equal violation of standards, MPCs [5]. So, for example, it is much more harmful to a human organism if the concentration of mercury compounds exceeds the standard five times than if the concentration of dust, petrol or carbon monoxide is as much higher. This is the

circumstance not usually known, and therefore often overlooked in integral pollution estimates.

In case of comparative comprehensive estimation of the air pollution of different towns or districts all possible pollutants should be considered before drawing conclusions. Generalized estimates are needed on the level of the whole republic, major towns, town districts and industrial centres for tactical as well as strategical decision-making.

3. Composite estimates of air pollution

In the Soviet Union the development of universal air pollution estimates was started about ten years ago by specialists of sanitary-hygiene, in the mid-1980s representatives of several other fields of science took up the problem [6, 7]. Nonetheless, in practice the above-described principles are still used, although thorough research has been conducted in the Soviet Union and other countries to change the traditional approach.

In the theory of the management and planning of national economy, including environmental protection, universal pollution estimates have not been introduced either, though the necessity of them has been discussed for years. In 1984 the need to conduct research in this field was discussed in the USSR Committee of Science and Technology. In 1985 the problem was considered at the USSR Central Institute of Mathematical Economics of the Academy of Sciences. Still next to no publications in this field have become available.

In 1980 the problem was formulated at the Institute of Economics of the ESSR Academy of Sciences, and a technique for comprehensive assessment of air pollution for planning and management needs was developed [8] that was based on several universally accepted sanitary-hygienic conceptions. The first a priori calculations based on this technique were made for the "Territorial scheme for rational exploitation of natural resources and environmental protection in Estonia" compiled in 1981.

This scheme was the first of its kind in the whole Soviet Union.

The above-mentioned methodological approach is based on a classification of the toxicity of air pollutants developed by M.A. Pinigin and his school at the A.N. Sytin Institute of General and Municipal Hygiene in Moscow [5, 9]. Namely, Pinigin et al. have compiled a classification of pollutants based on the relationship immission - duration of exposure for prolonged inhalation, in general this classification coincides with the grouping of pollutants for short-term (disrupted) exposure [5]. The latter has been worked out for labour protection, and is fixed in the respective sanitary-hygienic standards SN 245-71 [10]. This similarity enables to add groupings of hazardousness to the list of MPCs. To illustrate the classification of pollutants, some most typical chemical elements and compounds are given:

Class I : extremely toxic substances - mercury, lead, chlorine, ozone, cadmium oxide, etc.,

Class II : very toxic substances - hydrogen sulphide, carbon disulphide, nitrogen dioxide, hydrogen fluoride, etc.,

Class III: toxic substances - sulphur dioxide, phenol, methanol, tobacco dust, toluol, acetic acid, etc.,

Class IV: modestly toxic substances - dust (particulate matter), petrol, ammonia, carbon monoxide, acetone, etc.

On the basis of this classification health specialists have suggested the so-called composite index of air pollution hazardousness where different hazardousness of pollutants to human organism, different duration of the averaging of immissions and various interactions of pollutants - mutually independent effect, antagonism, summation and potentiation are taken into consideration [9]. By antagonism we refer to mutual reduction of the toxicity of pollutants, summation - summing up of toxicity of pollutants and potentiation - exponentiation of toxicity of pollutants. Such an index is one of the most perfect ones for estimating air quality from the standpoint of hygiene. Unfortunately, its practical application is hindered by the interactions mentioned and complicated assessment of the

respective coefficients.

A much simpler method for integral generalized assessment of air pollution has been suggested by the author [8, 11, 12] considering sanitary-hygienic requirements as well as the approach of a Canadian researcher H. Inhaber [13]. Namely, single air pollution indices may be synthesized into a composite index by means of a respective transformation system (of weights) based on the above-presented classification of pollutants according to their hazardousness, and rendering their hazardousness comparable to that of Class III. Such a system of weights is used to point out the fact that some pollutants make more harm to human organism than the others at the same level of exceeding the sanitary-hygienic limits (standards).

The system of transformations (weights) is based on equations cited in medical literature [14]. Let I_s denote how many times the concentration of pollutant s exceeds or which part it forms of its MPC. Let B_s stand for the transformation coefficient of pollutant s with respect to the standard or Class III. Now the standardization with regard to Class III is carried out using the following linear equations:

for substances of Class I:

$$B_s = 4.0 I_s - 3.0, \quad (1)$$

for substances of Class II:

$$B_s = 1.5 I_s - 0.5, \quad (2)$$

for substances of Class III:

$$B_s = I_s, \quad (3)$$

for substances of Class IV:

$$B_s = 0.75 I_s + 0.25, \quad (4)$$

So we can see, for example, that if the concentration of mercury vapour belonging among the most hazardous class of

substances exceeds the standard three-fold the pollution will be weighted as exceeding the standard nine-fold with respect to Class III. Three-fold excess of ammonia or carbon monoxide is weighted as only 2.5 fold violation of standards as these substances belong among modestly hazardous ones (Class IV).

Traditionally when dealing with assessment of single pollutant hazardousness the area of $I > 1.0$ is used. From the definition of MPC we can conclude that immissions higher than it (if pollutants are taken separately) damage human organism. As we do not consider various interactions between pollutants in the present study we use transformation (standardisation) of the different hazardousnesses only in the case when MPCs are violated.

When comprehensive assessment of air pollution is needed the immissions of registered pollutants are compared with the respective objectives, the MPCs of those pollutants, as a result the so-called subindices are obtained. To build up an integral air pollution index, these subindices, in their turn, are combined by the root-mean-square method. The advantages of this method are its simplicity and greater sensitivity with respect to extreme values of subindices as compared with linear averaging. The root-mean-square method tends to emphasize large subindices values mathematically, and so produces somewhat bigger values of a combined index than linear averaging does. When linear averaging is used, a big subindex value reflecting an undesirable pollution level, would tend to be "lost" when combined with other low value subindices. This is highly important to point out when taking into account the origin of harmful effects of air pollution to human organism.

The suggested approach yields transforming or weighting coefficients enabling to combine subindices higher than MPCs of pollutants of different hazardousness in one synthetic index.

To sum up, the composite air pollution index might be expressed in general by the following model:

$$I_t^p = F(I_{st}^p), \quad \text{if } I_{st}^p > 1.0 \quad (5)$$

and

$$I_t^p = \left(\sum_s (I_{st}^p)^2 / z \right)^{1/2}, \quad \text{if} \quad I_{st}^p \leq 1.0, \quad (6)$$

where I_{st}^p shows how many times the immission of pollutant s is higher than its MPC in town (region) p in year t ,

z - number of pollutants registered.

A more detailed description for a complex index of air pollution might be

$$I_t^p = \left(\left[\sum_s B_{st} \cdot (I_{st}^p)^2 \right] / \sum_s B_{st} \right)^{1/2}, \quad (7)$$

where

$$I_{st}^p = y_{st}^p / (MPC)_s \quad \text{and} \quad (8)$$

$$1) \quad B_{st} = f(I_{st}^p), \quad \text{if} \quad I_{st}^p > 1.0, \quad (9)$$

$$2) \quad B_{st} = 1, \quad \text{if} \quad I_{st}^p \leq 1.0, \quad (10)$$

where I_{st}^p has the same meaning as in formulae (5) and (6).

B_{st} - the weight of pollutant s with respect to the standard or Class III in year t ,

y_{st}^p - average yearly immission of pollutant s in town (region) p in year t ,

$(MPC)_s$ - maximum average permissible daily concentration pollutant s .

It can be concluded from the model that if air pollution is not over the MPCs for any pollutant, each pollutant will be transformed equally in hazardousness and air the pollution index will not be higher than 1.0 (see formula 10). Increasing pollution (see formulae 9) brings about index values higher than

simplified reflection of the reality. Bearing in mind the aim set - to create integral indices with different levels of generalization for the planning, management and monitoring of environmental components within the system of national economy planning (for greater detail see [15]) - the author has not found it necessary to consider various interactions of pollutants in the first approximation .

The air pollution index suggested here has a universal character - it can be used to give a generalized picture of the air pollution of a territorial unit of any size (town, administrative district, town district) during any period of time (a year, a month, a decade, a day). When the monitoring system is further improved, new indices may be added to the composite index.

Indices describing air pollution in various territorial units, e.g. towns or town districts may in their turn be aggregated into still more general aggregate indices. In so doing some territorial units may be given different weights depending on the prevailing priority criteria. The priority criteria are determined by the purpose of air pollution assessment. Analogously to the above-given model, the aggregate air pollution index may be expressed as follows :

$$\hat{I}_t = \left(\sum_p V^p \cdot (I_t^p)^2 \right)^{1/2} , \quad (11)$$

where I_t^p is air pollution index in town p in year t ,

V^p - the weight of town p determined on the basis of some priority criterion, say, according to the population that is likely to be affected to air pollution.

As the ultimate aim of the development of the society is man, and his health and comfort is to be ensured besides other means also by the existence of clean, uncontaminated environment,

the population number on the territory under study might be used as the weight as one alternative in finding the aggregate air pollution index.

When data on air pollution in all the major towns of a republic are available, a generalized regional estimate, composite air pollution index of the republic can be found. The dynamics of this index over a longer period is quite informative as it reflects the tendencies inherent in the atmospheric air pollution.

Comprehensive estimates like this enable to draw general conclusions about the efficiency of environmental protection measures. Wide-scale use of automated monitoring could thus give a much more adequate picture of the pollution of our towns and industrial centres than the ones available today.

4. CONCLUSIONS

The literature analyzed allows the author to draw the conclusion that the methods of compiling comprehensive air pollution estimates as well as their applications are quite heterogeneous. There are just a few methods, some of which are too complicated for practical applications, or applicable in narrow fields (see e.g. the medical men index), the others, on the contrary, are simplified to such a degree that they can become a source of misinformation. We still do not possess comprehensive air pollution estimates that are generalized enough to meet the needs of the planning and management of national economy and would thus be handy tools in our day-to-day work.

In the present paper the author has developed a novel method for generalized comprehensive assessment of air pollution on different levels of territorial division (region, town, town district, industrial centre, etc.). Integral indices are synthesized using the results of several sciences. An important new feature is the consideration of the concept of different hazardousness of pollutants to the human organism. This enables

to compare pollutants whose toxicity is quite different. To integrate single pollution indices into a synthetic index the method of mean squares suggested by H. Inhaber has been used.

Comprehensive estimates presented here should be tools satisfying the requirements of planning, design and management systems. For practical application of the indices easy-to-use though at the same time universal programmes have been made for a personal computer of the handy data processing system. The use of these programmes makes generalized air pollution assessment easy and, if necessary, it can be flexibly altered or supplemented.

The methods suggested have been used at the Institute of Economics of the Estonian Academy of Sciences to calculate the air pollution indices of three major North-Estonian towns, and on their basis, composite indices for a retrospective (1970 - 1986) and forecast period (1987 - 2005). For greater detail see the research carried out by the author at the Institute of Economics in 1988.

Graphical interpretation of comprehensive air pollution estimates that can be easily done by computers like IBM PC XT makes these easily understandable generalizations applicable with the help of bar graphs by the institutions controlling and directing environmental protection.

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NUMERICAL MODELING OF LOCAL ATMOSPHERIC FLOW AND AIR POLLUTION DISPERSION IN COASTAL AREAS OF THE BALTIC SEA

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Abstract. The mesoscale dispersion modeling system is under development with the purpose of investigating atmospheric flow and air pollution dispersion in coastal zones of the Baltic Sea. An example of numerical simulation of air pollution dispersion in the vicinity of the Zarnowiec nuclear power plant in northern Poland is presented. The mesoscale model is evaluated against measurement data from the Oresund experiment.

1. INTRODUCTION

In this decade, with the Bhopal and Chernobyl accidents, meteorology has come to play an increasing role in emergency response planning, particularly for those facilities handling toxic chemicals and radiological materials. The majority of emergency response modeling systems rely on Gaussian dispersion models based on the assumptions of a stationary and homogeneous atmosphere. However, such an approach has serious shortcomings in complex terrain and in coastal zones, especially within 15 km of the shoreline, where wind field and turbulence exhibit large spatial variability. A significant improvement may be achieved by application of a synoptic classification scheme and a mesoscale meteorological model coupled with a Lagrangian particle dispersion model [4]. Lyons and Fisher [3] identify several coastal mesoscale regimes with different transport and diffusion conditions. They propose a conceptual framework for allocating resources in developing an adequate emergency response system which should include three major factors: (1) the frequency of mesoscale regimes; (2) the extent to which the regime can result in high concentration/dosages; (3) the ease with which it can be modeled

with due considerations given for required input data. The frequently occurring events with the potential for significant impacts, and which are relatively easy to model should be given preference. This methodology allows one to focus efforts with given resources (time and funds) as well the limit of the current state-of-the-art of meteorology.

The above ideas are followed in developing meteorological research program for the nuclear power plant under construction on the shore of Lake Zarnowiec in northern Poland (Fig.1). Lake Zarnowiec lies in the coastal zone of the Baltic Sea in a valley oriented to SE in direction of some cities. The area of interest is characterized by influence of sea/land breeze circulation, hilly terrain (height differences up to 150m), and strong nonhomogeneities of the land surface.

The research program includes both field experiments and theoretical studies using a mesoscale meteorological model. Numerical modeling is expected: (1) to support planning dispersion field experiments and monitoring network, and (2) to provide recommendations for development of an emergency dispersion model to be used in the power plant.

The paper presents a current state of developing the mesoscale dispersion modeling system and its application for the Zarnowiec area. A preliminary evaluation of the mesoscale model was performed using data from the Oresund experiment.

2. MESOSCALE METEOROLOGICAL MODELING SYSTEM

The system of numerical mesoscale models (Fig.2) designed for the use on personal computers is under development at Department of Meteorology, Technical University of Warsaw. The objective of the system is investigating atmospheric flow and air pollution dispersion in the mesoscale including effects of terrain topography, large water bodies and urban areas.

The main part of the modeling system is the three-dimensional atmospheric boundary layer (ABL3) model with the following characteristics and configuration:

- primitive, hydrostatic equations formulated for meso-scale perturbations, 2- or 3-dimensional;
- terrain following coordinates;
- turbulence parameterization: second-order closure, modified Mellor-Yamada level 2.5 scheme;
- surface temperature: (1) prescribed or (2) calculated from the force-restore equation;
- initialization with 1-dimensional model version ABL1;
- numerical algorithm: finite difference implicate scheme, two-cycle splitting method;
- vertical resolution: 15 levels up to 2 km;
- horizontal resolution: telescoping grid mesh with $\Delta x=2\text{km}$ in the centre;
- time step: $\Delta t=120\text{s}$
- computation time for 1 hour of simulation and memory requirements (IBM PC/AT, 10MHz):
 - (1) $15 \times 12 \times 15$ gridpoints, 0.64 hour, 237 KB,
 - (2) $27 \times 23 \times 15$ gridpoints, 2.87 hour, 547 kB.

The ABL3 model creates wind and turbulence fields which can be used further as input data by dispersion models.

The Lagrangian dispersion model (LDM) included in the modeling system allows one to simulate pollution releases from a single point source by tracking the motion of particles or puffs. The particles representing discrete mass of pollutant are moved using the mean components of wind velocity obtained directly from the ABL3 model and the turbulent components derived from a first order Markov process. The puffs with the Gaussian distribution of pollutant mass are moved using mean wind fields only. The particle version of the LDM can be used as a visualization technique for the atmospheric flow in complex terrain predicted by the ABL3 model.

The models are associated by a program environment containing programs for data preprocessing and a graphi-

cal presentation of results. All programs are written in the FORTRAN-77 standard and implemented on the IBM PC/AT compatible microcomputer. The detailed description of the modeling system is available from the author [5].

3. SIMULATIONS FOR THE ZARNOWIEC AREA

The most complicated pattern of air pollution dispersion in the Zarnowiec area can be expected under weak wind conditions with strong thermal contrast between sea and land. Pollution dispersion is driven then by an interaction of synoptic flow and sea/land breeze circulation. As an example the results of numerical simulation performed for a cloudless Summer day with a weak western geostrophic wind (5m/s) are presented below.

Fig.3 shows simulated surface wind fields on morning and on afternoon. Some disturbances of wind field at 10:00 are due to terrain topography and surface non-homogeneity. Four hours later when the land surface becomes about 10 degrees warmer then the sea a visible effect of sea breeze appears with the onshore wind component up to 10km inland.

The mean wind velocity and velocity variances simulated by the ABL3 model were used to run the particle version of the LDM for a continuous pollution releases at Zarnowiec from the heights 50m and 300m. The center-lines of pollution plumes are obtained by tracking a set of particles without taking into account the turbulence. Fig.4 demonstrates significant changes of the plume direction during the day. The rise and descending of the nonbuoyant plume are caused by upward motions over warm land and downward motions over cold sea. The pollution plume shown in Fig.5 was simulated including turbulence with the aid of an larger set of particles .

After the model validation, the similar simulations will be performed for different synoptical conditions in order to provide an operational guidance for planning tracer experiments.

4. SIMULATIONS OF THE ØRESUND EXPERIMENT DATA

A series of meteorological and tracer experiments was carried out during May and June 1984 over the 20km wide Øresund strait between Denmark and Sweden (Fig.1) with the purpose of (1) investigating turbulence and atmospheric dispersion over cold water and warm land surfaces and (2) providing the data needed to evaluate mesoscale models in a coastal environment. The land area is nearly flat. On the western side of the Øresund lies Copenhagen with high surface roughness.

The ABL3 model was used to simulate measurements on June 5 of the Øresund experiment with moderate easterly winds. Since the coastline on both sides of the strait is rather straight and the two coastlines are almost parallel, the 2-dimensional model version is applied along a traverse indicated by a thick line in Fig.1. The modeling domain 150*2km with 50*15 gridpoints was extended eastward to include the Baltic Sea. The land surface was assumed to be flat with variable roughness and surface temperature was prescribed as a function of time [1]. The geostrophic wind velocity and another synoptic variables were constant during the simulation performed from 6:00 to 12:00 CET.

The air is slightly unstable upwind from the Øresund strait over Swedish coast, then it gradually turns stable as it passes over the cold water surface. This stable stratification is quickly turned into an unstable one downwind from the Øresund over Copenhagen. Fig.6 presents simulated wind velocity and turbulence intensity (dissipation ratio of turbulent energy $\epsilon^{1/3}$ [$\text{cm}^{2/3} \text{s}^{-1}$]) plotted against data obtained from sodars, masts and an airplane.

When passing over the Øresund, the wind at 100m gradually speeds up, reaching the maximum near the Danish coast then it decreases over the rough Copenhagen area. The surface wind has a different structure. The

10m wind first accelerates over the Swedish coast, and then begins to decelerate reaching the minimum over Copenhagen. Over the more smooth farmland west of Copenhagen the wind speed again increases. The simulated tendency in wind speed agree with the measurement data. The surface wind direction is simulated with accuracy of 10-15 degrees. The gradual lowering of turbulence at level 300m as air passes the Öresund is well simulated by the model.

The model is able to correctly reproduce a general structure of the ABL over the land-water-land area. An improvement of the model result can be expected from (1) better representation of terrain (3-dimensional simulation including topography), and (2) more realistic representation of synoptic conditions (geostrophic wind variable with time and height).

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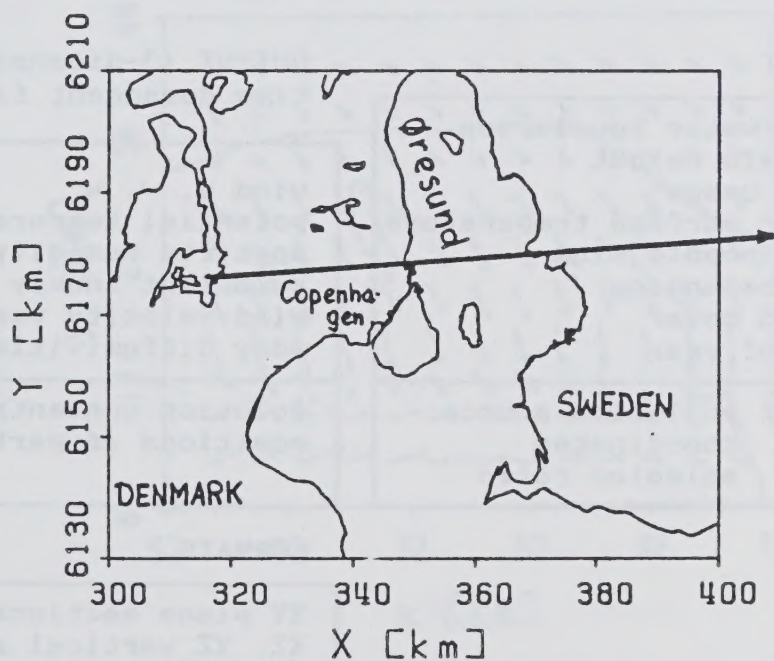
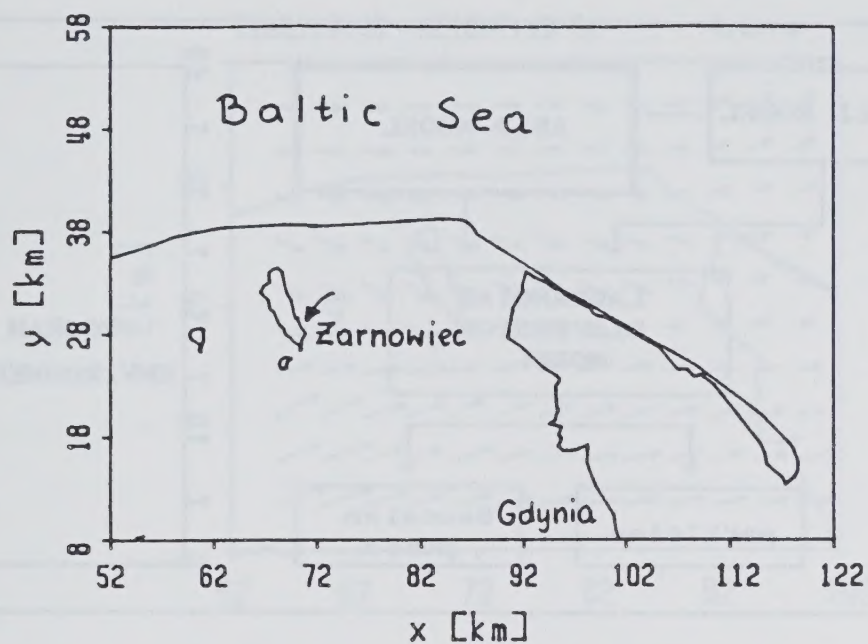
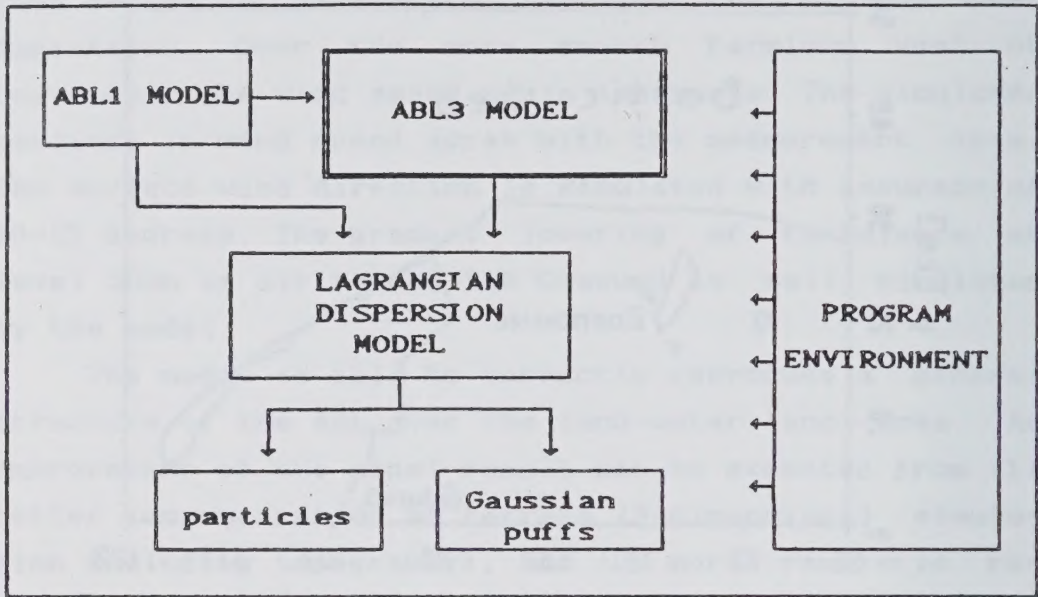


Fig.1. Coastal zone of the Baltic Sea in vicinity of the Zarnowiec nuclear plant (top) and the strait of Øresund and its surroundings (bottom)

**INPUT**

land/water boundaries
 terrain height
 land usage
 water surface temperature
 geostrophic wind
 radiosounding
 cloud cover
 day of year

point pollution source:
 coordinates
 emission ratio

OUTPUT (3-dimensional time dependent fields)

wind u , v , w
 potential temperature
 specific humidity
 turbulent energy
 wind velocity variances
 eddy diffusivities

pollution concentration
 positions of particles

FORMATS

XY plane sections
 XZ, YZ vertical sections
 X, Y, Z profiles

Fig. 2. Mesoscale dispersion modeling system

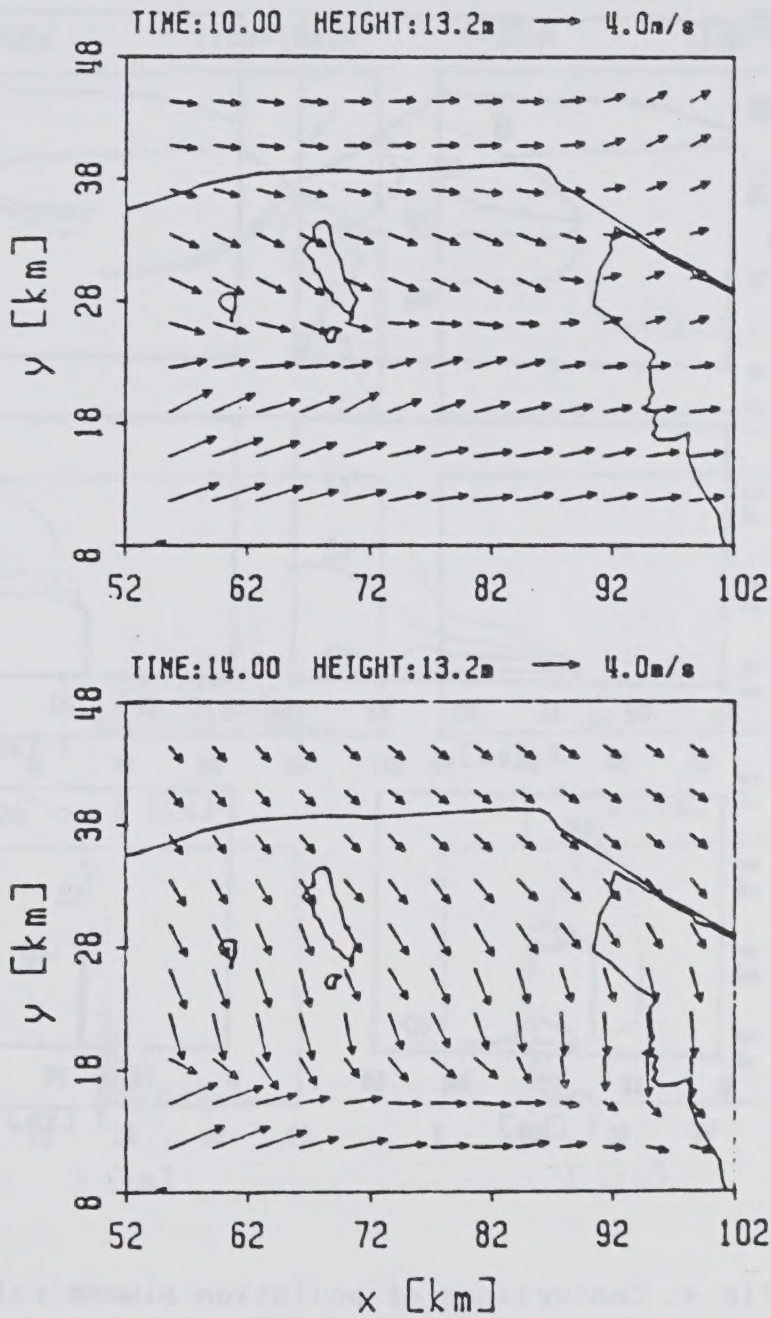


Fig. 3. Surface wind fields in the Zarnowiec area

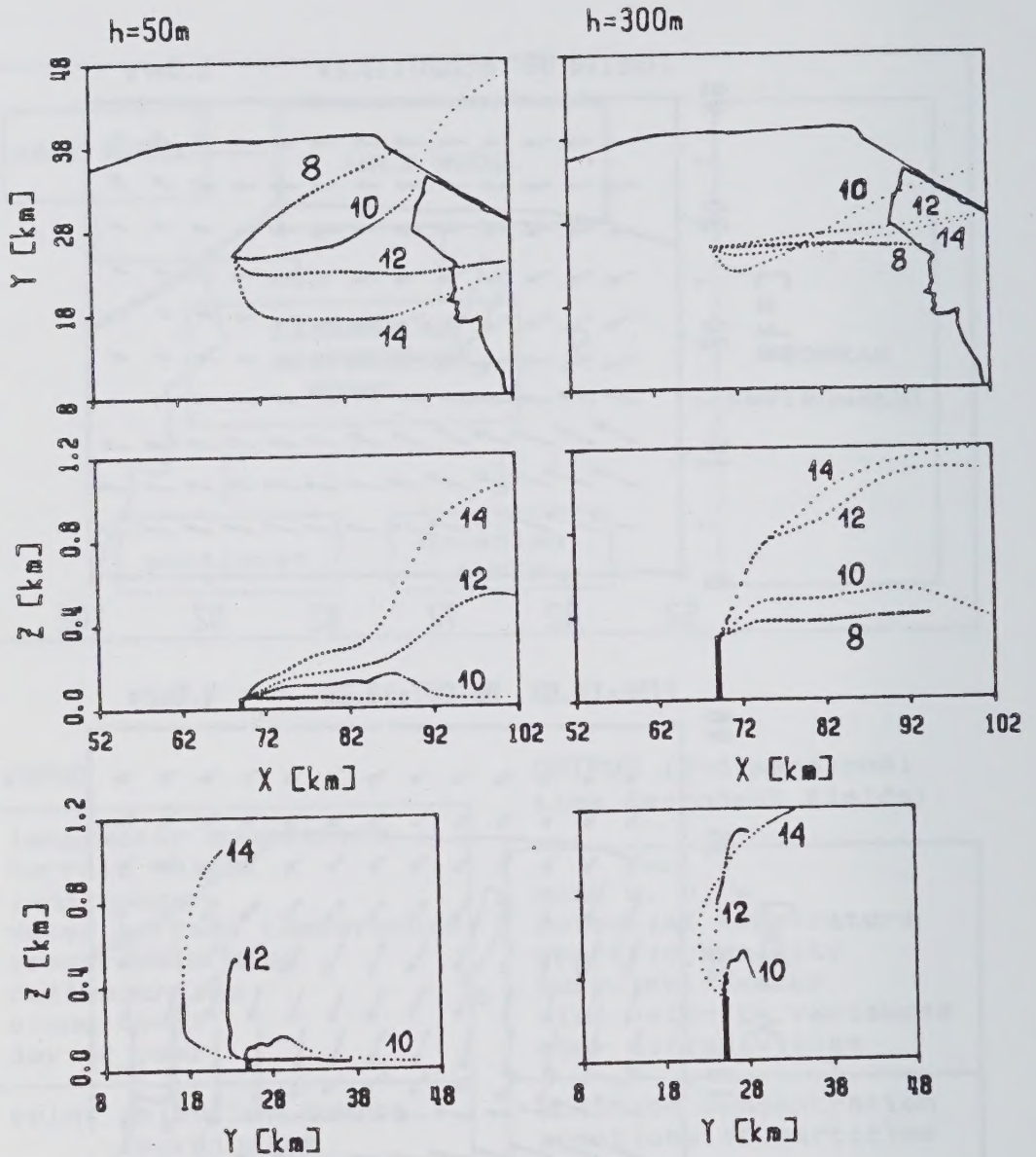


Fig.4. Centerlines of pollution plumes released from 50m and 300m stack at Zarnowiec as viewed in xy section (top), xz section from South (middle), and yz section from East (bottom), numbers denote local time

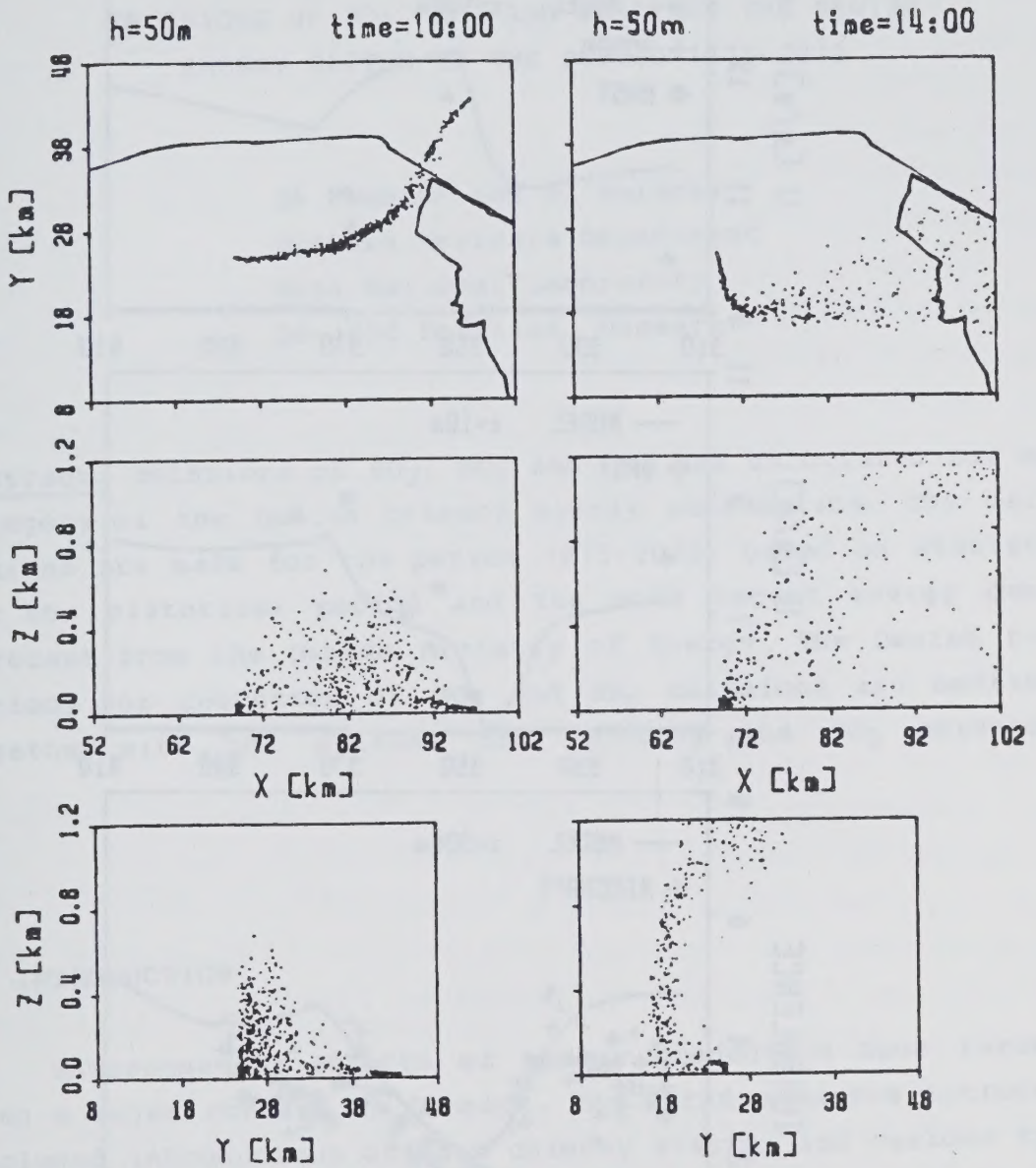


Fig.5. Pollution plume released from 50m stack at Zarnowiec as viewed in xy section (top), xz section from South (middle), and yz section from East (bottom) at 10:00 and 14:00 LST

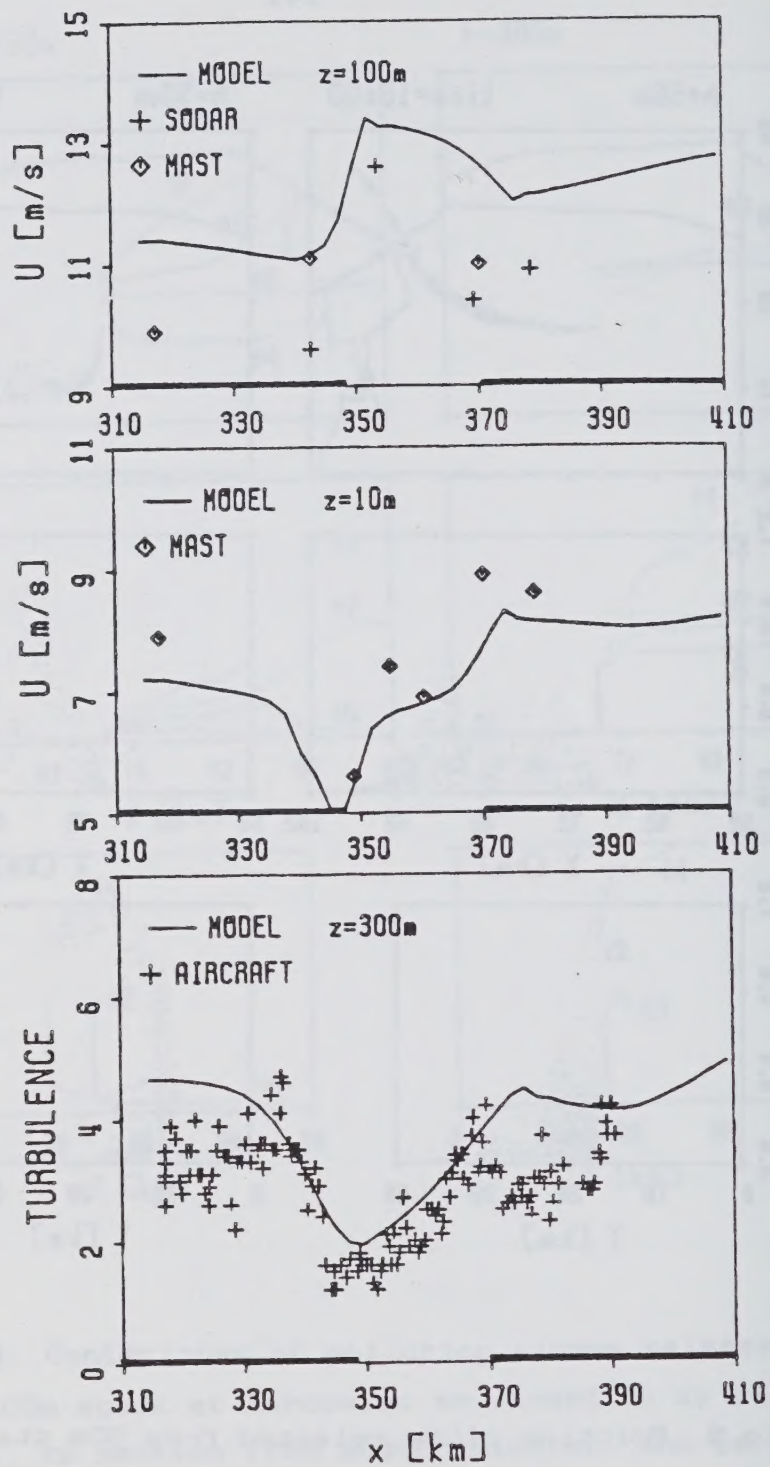


Fig. 8. Comparison of simulated wind velocity at $z=10\text{m}$ and $z=100\text{m}$, and turbulence with measurement data from the Öresund experiment (June 5, 1984)

EMISSIONS OF SO_2 , NO_x AND CO_2 FROM THE DANISH
ENERGY SECTOR IN THE PERIOD 1975-2010

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Abstract. Emissions of SO_2 , NO_x and CO_2 are calculated for each category of the Danish primary energy consumption. The calculations are made for the period 1975-2010, based on statistics for the historical period and the most recent energy demand forecast from the Danish Ministry of Energy. The Danish regulations for reduction of SO_2 and NO_x emissions are mentioned together with the options for reducing the CO_2 emissions.

1. INTRODUCTION

Environmental effects of energy production have recently been a major concern in Denmark. The first measures introduced included introduction of high chimney stacks, and various types of filters for absorption of particulates. More recently concern has turned to a wider range of substances emitted as a result of energy use, causing both local and more long range damage.

In this paper the emissions of SO_2 , NO_x and CO_2 from the Danish energy system are calculated for the period 1975 to 2010. The basis is the official statistics for the historical period and projections for the primary energy consumption until 2010 made by the Danish Energy System model (DES) at Risø, using the most recent energy demand forecast from the Ministry of Energy.

For each category of primary energy consumption (power-plants, district heating plants, process sector, individual heating units, transportation and others) the emissions were calculated. The primary energy consumption was split into fuel types and then multiplied with a set of emission factors constructed in a dialogue with the National Agency of Environmental Protection.

Section 3 describes the primary energy consumption in the period 1975-2010 and some of the reasons for the changes in the Danish energy consumption pattern. Section 4 and 5 mention the Danish regulations for reduction of SO_2 and NO_x emissions and show the resulting emissions from the energy sectors. Section 6 treats the CO_2 emissions some options in connection with the report "Our Common Future" from the "Brundtland-commission". A set of tables is shown in the annexe.

2. ENVIRONMENTAL AND ENERGY PLANNING PROBLEMS IN DENMARK

Environmental side effects as well as economic consequences are becoming a more and more important subject for Danish energy planning. The energy planning which has been taken place in Denmark since the first oil crisis in 1974 has in some respect already had a positive environmental effect. Examples of this positive effect are:

- Significant reductions of the space heating demand through better building insulation and more energy economic behaviour of the consumers.
- The establishment of CHP systems and district heating systems.
- Introduction of natural gas.
- Increased energy efficiencies in the industry.

The consequence of this is mainly that the general growth rate in the energy consumption has been reduced. Furthermore, the structural changes in the energy conversion system and in the primary fuel requirements have been in accordance with the need for sulphur dioxide reductions.

However, important environmental side effects of the Danish energy system must be further handled in the future. These include:

- The need for reduction of the NO_x emissions from road traffic in urban areas, from larger industrial plants and from power plants.
- The special emission problems from waste combustion plants and some chemical plants with dioxin, hydrocarbons, heavy metals and other.
- The problems of emissions of polycyclic aromatic hydrocarbons and other substances from low stack sources.
- The CO_2 emissions which are connected to all use of fossil fuels.

Technical solutions in the form of cleaning systems for all these problems have not yet been developed in an economically viable form. Nevertheless, some of the emissions can be reduced by fuel substitution, for instance from coal to natural gas. Emphasis has therefore been given in the Danish energy planning to investigate the possibilities of energy savings.

3. THE DANISH ENERGY CONSUMPTION

A picture of the Danish energy system is shown in figure 1. The primary energy consumption decreased after the second oil crisis in 1979 and has increased slowly since 1981 to a level about 750 PJ in 1986.

PRIMARY ENERGY, PJ

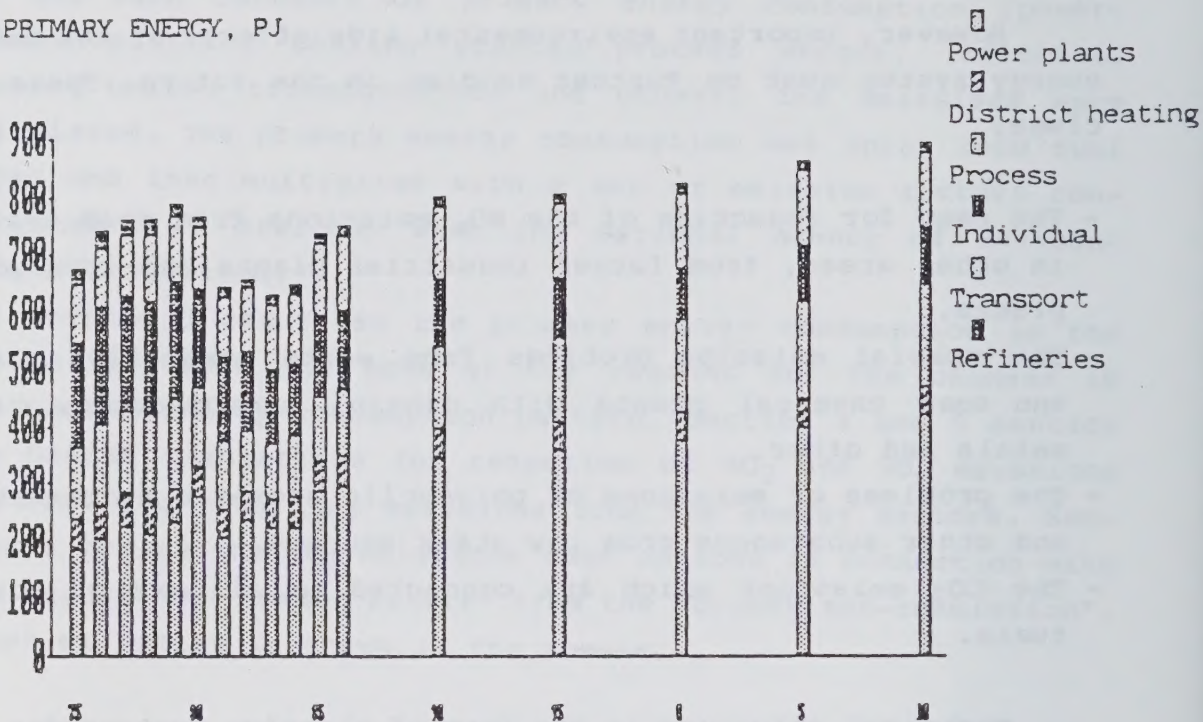


Figure 1. Primary energy consumption in Denmark

The energy consumed by the power plants is used to produce both electricity and heat. The process sector includes manufacturing, agriculture, fishing and construction. Fuel bought for international sea and air transportation is shown in a separate column in table 1 (see annexe).

4. EMISSIONS OF SO_2

The Danish regulations for reduction of SO_2 emission are based on different principles for the power sector and for the rest of the energy system. The Danish act on limitation of sulphur dioxide pollution from power plants is based on the principle that the Minister for the Environment, on the basis of information from the power companies, must lay down a limit for the maximum amount of SO_2 which can be emitted annually from Danish power plants.

The Minister has stated that the total annual emission from the power plants will be regulated in such a way that it must be reduced to 125,000 ton/year in 1995, provided that the assumptions underlying the cost estimates are not invalidated, and that the international development does not present unexpected supply difficulties. It is accordingly left to the power companies among themselves to decide the most economic way to achieve this goal, this policy is often referred to as the "bubble policy." It has been agreed that in coming years all new and some old Danish power plants will be equipped with flue-gas desulphurization.

In the other energy sectors emission reduction regulations are not based on emission measurements but on reductions of the sulphur content in the fuel:

- The sulphur content in gas oil was reduced from 0.5% to 0.3% by October 1, 1985, and to 0.2% by May 1, 1988.
- The sulphur content in fuel oil was reduced from 2.5% to 1.5% by October 1, 1985 (for Greater Copenhagen the limit of 1% was unchanged). The sulphur content was further reduced to 1% by January 1, 1988.
- An upper limit for sulphur in coal used in other facilities than power plants was fixed to 1.2% by October 1, 1985, and reduced to 0.9% by May 1, 1988.
- Fuel used by refineries must not give rise to a sulphur emission which exceeds the level allowed when using the corresponding amount of fuel oil.

It is possible to obtain exemptions from these regulations on sulphur in fuels, subject to certain documentation. For example that the combustion technique employed or desulphurization of the flue-gas ensures that the sulphur dioxide emission does not exceed the limit specified in the regulations. This is the case for the cement industry, for instance.

The result of the calculations of the total SO₂ emissions is shown in figure 2. The effect of the above mentioned regulations is clearly seen. The emissions from the power plants are calculated for 1975-82, measured for 1983-86 and set equal to

the maximum allowed for 1990-2010. The total emission of SO_2 has been reduced by 32% in the period 1975-86. Table 3 in the annexe shows the total SO_2 emissions in detail.

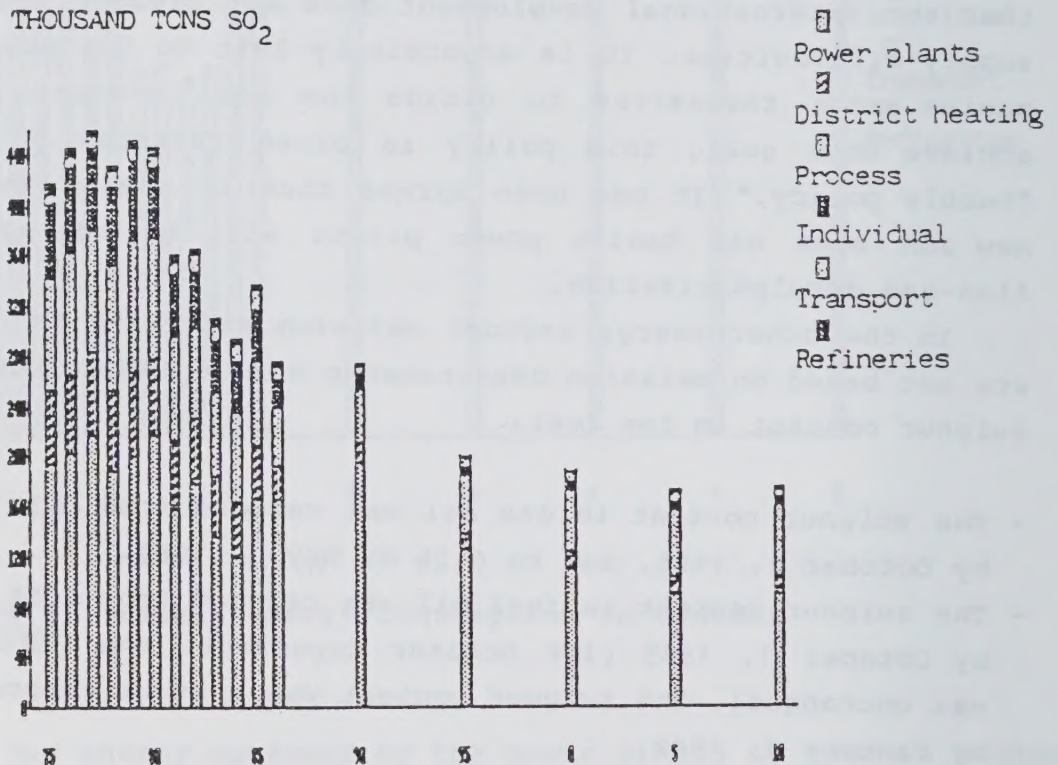


Figure 2. SO_2 emissions from the Danish energy sectors

5. EMISSIONS OF NO_x

There is at present no Danish legislation on reductions of NO_x emissions. Nevertheless, the National Agency of Environmental Protection has, in the approval of four projects concerning construction or modification of power plants to be put into operation in the period 1986-1991, required that low- NO_x techniques are applied.

The emissions of NO_x from power plants are calculated for the period 1975-86 and for 1990-2010 the maximum allowed according to the new EEC directive was used.

The calculations are made in agreement with the intention of the Danish government that from 1990 new cars imported to Denmark must comply with the current US-standards. In practice this may mean the use of 3-way catalytic converters.

The results of the calculation of the total NO_x emissions are shown in figure 3. The NO_x emissions from power plants have increased due to the switch from oil to coal. The emission from the transportation sector (see table 7) is the second largest with 35% of the total emission of 260,000 tons in 1986.

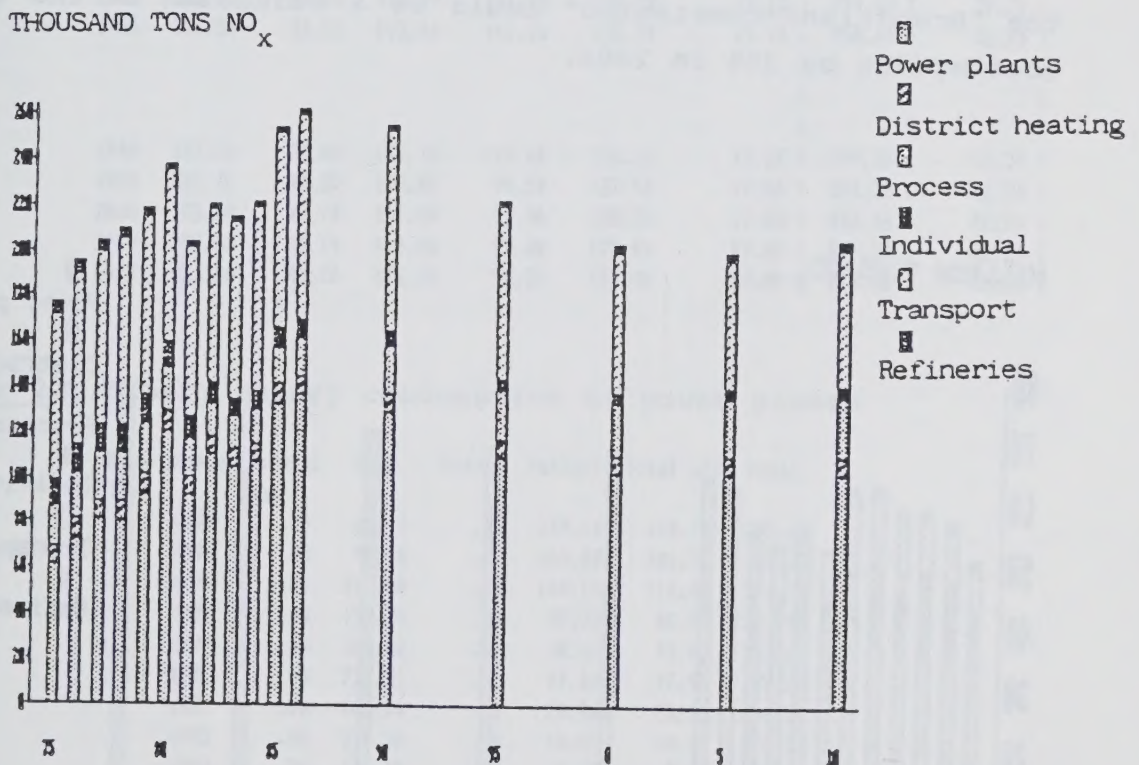


Figure 3. NO_x emissions from the Danish energy sector

6. EMISSIONS OF CO_2

The emission factor for CO_2 for oil is about 75% of the emission factor for coal, and for natural gas it is only about 55%. Increased use of natural gas will therefore decrease the

CO₂ emissions significantly, this effect can be seen in individual heating (see table 8) where the use of natural gas is increasing in the period 1985-2000. Figure 4 shows the CO₂ emissions from the different sectors. The total emission in 1986 was about 64 million tons of which 46% came from the power plants.

Since there is no known way of removing the CO₂ from the flue gas, other ways must be found to decrease these emissions. The options for Denmark will be a reduction of the energy consumption, increased energy efficiency and fuel switch towards natural gas and introduction of more renewable energy, mostly wind power. A first step in the direction of the goals set by the "Brundtland-commission" could be a reduction of the energy consumption by 20% in 2005.

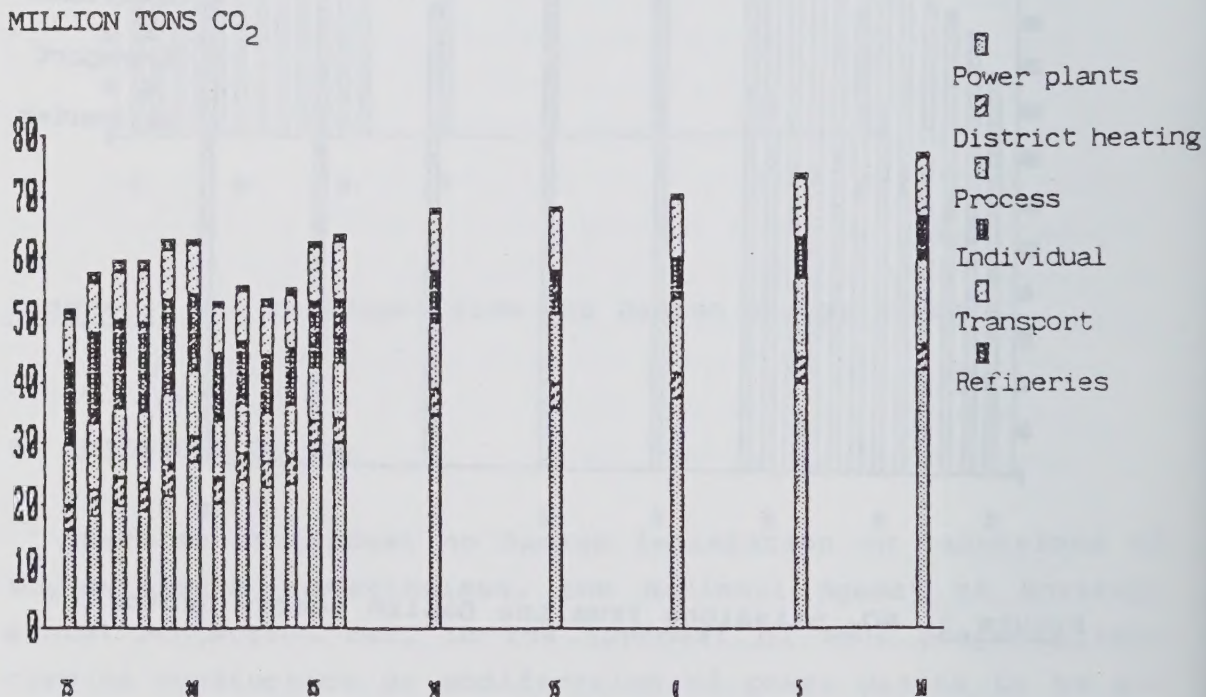


Figure 4. CO₂ emissions from the Danish energy sector

ANNEX

Table 1. Total primary energy consumption in Denmark

Total (PJ)	Power- plants	Dist.heat. plants	Proces heating	Individual heating	Transport Domestic	Refineries & others	Total	Transport internat.
1975	185.60	53.55	126.12	181.11	101.78	28.47	676.63	44.38
1976	205.33	57.23	139.23	204.39	105.63	27.93	739.74	45.59
1977	224.39	58.50	144.32	198.53	106.09	26.92	758.75	44.30
1978	212.07	59.03	149.03	197.07	116.50	24.31	758.00	46.14
1979	233.62	60.79	153.51	203.70	113.14	22.48	787.24	43.32
1980	276.88	53.69	138.89	168.63	108.43	15.88	762.40	40.29
1981	206.30	50.24	118.97	147.17	104.96	16.56	644.19	40.73
1982	239.52	49.80	106.18	138.53	110.18	14.61	658.82	41.48
1983	224.41	48.52	101.00	128.60	111.16	18.48	632.17	39.37
1984	227.31	50.22	109.97	123.52	118.52	17.73	647.27	40.12
1985	286.63	54.90	112.79	141.95	121.29	17.11	734.67	39.71
1986	296.54	51.53	115.66	141.36	125.94	19.14	750.17	42.24
1990	347.30	53.00	139.70	115.60	126.16	17.80	799.56	42.24
1995	357.70	49.30	149.00	99.50	127.96	17.80	801.26	42.24
2000	375.00	49.70	159.90	91.40	128.86	17.80	822.66	42.24
2005	398.90	49.70	168.80	95.30	129.06	17.80	859.56	42.24
2010	422.20	49.70	176.40	99.50	127.96	17.80	893.56	42.24

Table 2. Primary energy consumption of power plants

Powerplants (PJ)	Natural gas	Coal	Gasoil	Fueloil	Total oil	Total
1975	.00	67.41	.08	118.11	118.19	185.60
1976	.00	98.40	.04	106.89	106.93	205.33
1977	.00	113.90	.33	110.15	110.49	224.39
1978	.00	123.50	.34	88.23	88.57	212.07
1979	.00	154.50	.30	78.82	79.12	233.62
1980	.00	228.95	.26	47.67	47.93	276.88
1981	.00	181.00	.34	24.96	25.30	206.30
1982	.00	221.20	.30	18.02	18.32	239.52
1983	.00	215.50	.39	8.52	8.91	224.41
1984	.00	220.10	.30	6.91	7.21	227.31
1985	3.17	270.00	.13	13.33	13.46	286.63
1986	5.56	276.50	.22	14.26	14.48	296.54
1990	13.30	321.90	0	12.10	12.10	347.30
1995	13.30	330.60	0	13.80	13.80	357.70
2000	13.30	347.20	0	14.50	14.50	375.00
2005	13.30	370.20	0	15.40	15.40	398.90
2010	13.30	392.50	0	16.40	16.40	422.20

The primary energy consumption is the amount used in Denmark and not corrected for import/export.

Table 3. Total emission of SO₂ from the Danish energy sector

Total SO ₂ (Ton)	Power plants	Dist.heat. plants	Process	Individual heating	Transport domestic	Refineries & others	Total	Transport internat.
1975	194387	59362	88554	58931	9192	6299	410426	20861
1976	202624	63797	96681	66898	9589	5570	439589	20332
1977	217807	65109	97388	66240	8924	4956	455468	17455
1978	188788	65604	98478	63379	10899	4617	427148	17168
1979	200204	67756	104151	63703	11025	5839	446838	15673
1980	217893	59667	96843	55069	11385	4497	440856	14684
1981	157795	54699	83089	48116	11267	4935	354966	17425
1982	178595	52465	70428	45982	13613	3574	361083	16456
1983	137000	48488	66746	40263	12638	4427	305135	14254
1984	120000	45219	70470	40265	13606	3896	289560	14927
1985	167000	42803	66006	41195	15017	4342	332021	14278
1986	167000	25530	46583	23125	10292	2449	272530	10522
1990	195000	16855	42603	10562	6446	1620	271466	10522
1995	125000	13783	45074	7639	6572	1620	198069	10522
2000	110000	13819	49287	6226	6680	1620	186013	10522
2005	90000	13819	52776	6577	6779	1620	169952	10522
2010	90000	13819	55703	6955	6896	1620	173374	10522

Table 4. Emissions of SO₂ from power plants

Powerplants (Ton SO ₂)	Natural gas	Coal	Gasoil	Fueloil	Total oil	Total	Max Allowed	SO ₂ % in coal	El.import GWh	El.production GWh	Emission ton/GWh
1975	0	48148	19	146220	146239	194387		1.00	1066	17848	10.89
1976	0	70286	10	132329	132338	202624		1.00	830	19212	10.55
1977	0	81357	79	136372	136450	217807		1.00	629	20704	10.52
1978	0	88214	80	100494	100574	188788		1.00	3680	19131	9.87
1979	0	110357	71	89776	89846	200204		1.00	3114	20701	9.67
1980	0	163536	61	54296	54357	217893	212000	1.00	-1237	25133	8.67
1981	0	129286	80	28429	28509	157795	215000	1.00	5536	18083	8.73
1982	0	158000	71	20525	20595	178595	215000	1.00	2028	22028	8.11
1983	0	127204	92	9704	9796	137000	215000	.82	4207	20357	6.73
1984	0	112059	71	7870	7941	120000	200000	.71	4884	20804	5.77
1985	0	151787	31	15183	15213	167000	200000	.78	460	26867	6.22
1986	0	150727	31	16242	16273	167000	195000	.76	82	28330	5.89
1990						195000	195000				
1995						125000	125000				
2000						110000	110000				
2005						90000	90000				
2010						90000	90000				

The emissions of SO₂ are calculated for 1975-82, measured for 1983-1986 and for 1990-2010 equal to max allowed.

Table 5. Total emission of NO_x from the Danish energy sector

Total NO _x (Ton)	Power plants	Dist.heat. plants	Process heating	Individual heating	Transport domestic	Refineries & others	Total	Transport: internat.:
1975	60710	8009	18798	11288	72801	4971	171607	25443
1976	72890	8569	20257	12775	75412	5232	189902	25910
1977	81143	8751	20915	12507	75718	4907	199033	24067
1978	80489	8830	21402	12072	82039	4710	204832	24967
1979	93107	9102	22037	12358	78724	3859	215327	22662
1980	121363	8044	19953	10653	75684	2339	235697	21672
1981	92904	7625	17249	9404	74426	2375	201608	23304
1982	110531	7568	15428	8986	75946	2013	218459	23668
1983	105524	7496	14402	8138	77239	2978	212799	21834
1984	107336	7861	15907	8177	80188	2863	219470	21963
1985	133573	8761	16064	8855	84893	2941	252145	21469
1986	137499	8221	16201	8395	89705	2994	260020	23061
1990	130000	8209	20979	6230	87705	2994	253123	23061
1995	110000	7417	22443	5075	75705	2994	220640	23061
2000	103000	7457	24342	4570	61705	2994	201075	23061
2005	103000	7457	25932	4765	56705	2994	197859	23061
2010	103000	7457	27337	4975	60705	2994	203474	23061

Freestilling af salpetersyre ved oxidation (forbrænding) af importeret ammoniak (NH₃) giver et tab af NO₂ til atmosfæren på 735 ton NO_x/år.

Table 6. Emissions of NO_x from power plants

Powerplants (Ton NO _x)	Natural gas	Coal	Gasoil	Fueloil	Total oil	Total	Max allowed	El.import GWh	El.production GWh	Emission ton/GWh
1975	0	32356	0	28346	28354	60710		1066	17848	3.40
1976	0	47232	4	25653	25658	72890		830	19212	3.79
1977	0	54672	33	26437	26471	81143		629	20704	3.92
1978	0	59280	34	21175	21209	80489		3680	19131	4.21
1979	0	74160	30	18917	18947	93107		3114	20701	4.50
1980	0	109896	26	11441	11467	121363	115000	-1237	25133	4.83
1981	0	86880	34	5990	6024	92904	120000	5536	18083	5.14
1982	0	106176	30	4325	4355	110531	125000	2028	22028	5.02
1983	0	103440	39	2045	2084	105524	130000	4207	20357	5.18
1984	0	105648	30	1658	1688	107336	130000	4884	20804	5.16
1985	761	129600	13	3199	3212	133573	135000	460	26867	4.97
1986	1334	132720	22	3422	3444	137499	140000	82	28330	4.85
1990						130000	130000			
1995						110000	110000			
2000						103000	103000			
2005						103000	103000			
2010						103000	103000			

Table 7. Emissions of NO_x from transportation

Transport (Ton NOx)	Roadtransport			total	Railway	Seatransport			Airtransport		Total
	Diesel	Gasoline	LPG		Diesel	Fueloil	Diesel	Diesel	J.P.1	Gasoline	
					Total	Ferries	Others				
1975	10586	52368	1231	64185	2562	1523	2300	1854	226	151	72801
1976	10975	54960	713	66648	2587	1704	2129	1854	339	151	75412
1977	10564	55770	1264	67599	2537	1487	2197	1270	477	151	75718
1978	13968	57307	1563	72839	2484	1611	2345	2058	549	153	82039
1979	15232	53870	1594	70697	2586	1499	2132	1123	534	153	78724
1980				68000	2718	1576	2132	910	195	153	75684
1981				67000	3282	1438	1960	525	105	117	74426
1982				67000	3588	2347	2066	738	90	117	75946
1983				69000	3204	1645	1788	1263	222	117	77239
1984				73000	3126	1221	1296	1222	171	153	80188
1985				77000	2946	2165	1648	836	144	153	84893
1986				81000	2970	2936	1747	738	198	117	89705
1990				79000	2970	2936	1747	738	198	117	87705
1995				67000	2970	2936	1747	738	198	117	75705
2000				53000	2970	2936	1747	738	198	117	61705
2005				48000	2970	2936	1747	738	198	117	56705
2010				52000	2970	2936	1747	738	198	117	60705

Table 8. Total emission of CO₂ from the Danish energy sector

Total CO ₂ (Kton)	Power plants	Dist.heat. plants	Process heating	Individual heating	Transport domestic	Refineries & others	Total	Straw part of total	Transport internat.
1975	15622	4179	9749	13408	7286	1816	52059	77	3206
1976	17950	4451	10770	15133	7561	1785	57648	77	3292
1977	19794	4545	11258	14721	7587	1713	59617	115	3191
1978	19151	4586	11595	14633	8348	1559	59872	153	3324
1979	21614	4717	11968	15164	8115	1423	63001	306	3116
1980	26900	4191	10820	12658	7787	984	63340	612	2902
1981	20334	3990	9326	11110	7543	1025	53328	765	2942
1982	23918	4031	8420	10500	7930	899	55698	1010	2996
1983	22640	4108	7970	9761	7997	1158	53634	1076	2840
1984	22984	4361	8821	9376	8537	1094	55173	1107	2892
1985	28716	4726	8989	10675	8737	1068	62912	1137	2861
1986	29591	4426	9124	10485	9085	1179	63890	1148	3044
1990	34486	4409	10766	8447	9092	1107	68307	1530	3044
1995	35499	4096	11478	7228	9223	1107	68632	1928	3044
2000	37244	4126	12381	6575	9291	1107	70725	1928	3044
2005	39657	4126	13105	6864	9309	1107	74169	1928	3044
2010	42005	4126	13734	7175	9236	1107	77383	1928	3044

Table 9. Emissions of CO₂ from power plants

Powerplants (Kton CO ₂)	Natural gas	Coal	Gasoil	Fueloil	Total oil	Total	El.import GWh	El.produ GWh	Emission kton/GWh
1975	0	6876	6	8740	8746	15622	1066	17848	.88
1976	0	10037	3	7910	7913	17950	830	19212	.93
1977	0	11618	25	8151	8176	19794	629	20704	.96
1978	0	12597	25	6529	6554	19151	3680	19131	1.00
1979	0	15759	22	5833	5855	21614	3114	20701	1.04
1980	0	23353	19	3528	3547	26900	-1237	25133	1.07
1981	0	18462	25	1847	1872	20334	5536	18003	1.12
1982	0	22562	22	1333	1356	23918	2028	22028	1.09
1983	0	21981	29	630	659	22640	4207	20357	1.11
1984	0	22450	22	511	534	22984	4884	20004	1.10
1985	180	27540	10	986	996	28716	460	26867	1.07
1986	316	28203	16	1055	1072	29591	82	28330	1.04
1990	757	32834	0	895	895	34486			
1995	757	33721	0	1021	1021	35499			
2000	757	35414	0	1073	1073	37244			
2005	757	37760	0	1140	1140	39657			
2010	757	40035	0	1214	1214	42005			

WASTE

COMPUTERIZED MANAGEMENT OF INDUSTRIAL SOLID WASTE

- the case of the city of Copenhagen.

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Abstract This introduction will give a short presentation of a project concerning the development of an information system for control and supervision of industrial solid wastes. The background for the project is the increasing need to restrict the amount of wastes and the strain on the environment resulting from the growing amount of wastes. In the legislation, requirements are made for the municipalities to register and recover wastes, including hazardous wastes.

The strategies of The Local Office of Environmental Protection, The City of Copenhagen in relation to a regulation of industrial wastes will be outlined briefly, especially as regards the possibilities of recycling the industrial wastes (with a view to manufacturing high-quality products), combustibility (with a view to replacing other sources of energy), and detection of hazardous wastes. It has been found that the analysis of sources, registration and classification of the industrial wastes will be central tasks.

The physical (logistic) system is rather complex, as it includes both production, distribution and disposal of the wastes and is at the same time under continuous change. A computer-based information system is therefore in the developing process. Such a system is being designed especially for solving of the problems of The Local Office of Environmental Protection, The City of Copenhagen in connection with control and decision related to industrial solid wastes. The information system should be flexible, user-friendly and be capable of being implemented in a PC-environment.

1. Introduction.

The issue of waste management and the protection of the environment is a very urgent matter and one of great public interest in Denmark. The environmental problems have only gradually been recognized over the last 15 years. There are three major problems: hazardous wastes, the impact of refuse dumps on the surrounding environment, and the pollution created by the incineration process.

During the last four years a number of initiatives have been started at The Local Office of Environmental Protection, The City of Copenhagen, both to satisfy the demands of the Danish Environmental Protection Act and the Reclamation and Recycling Acts, and the growing need to reduce the amount of waste and hereby the related environmental problems.

This paper gives a short presentation of a project concerning the development of a management information system for decision-making, supervision and control of industrial solid waste. This is one of the many activities that The Local Office of Environmental Protection has started with the objective to develop an optimal waste management policy from an environmental viewpoint subject to the economic resources available.

A main aspect to achieve this objective is the recognition of the fact that industrial waste, both in what concerns quantity and composition is susceptible to influence. That is the mere registration of industrial waste should evolve to a more active regulation/ steering function to achieve the objectives of the local authorities.

Let us now see more specifically at The Local Office of Environmental Protection's strategies for waste management in Copenhagen.

2. Strategies for waste management.

Shortly described, the principal strategies for waste handling, reclamation and recycling are the following:

- a) To sort out at the source hazardous wastes, so that hazardous wastes should be reclaimed and recycled as far as possible.
- b) Reclamation and recycling initiatives for waste based on sorting out at the source, for instance some activities are going on in what concerns cardboard and paper. The main principle is to produce goods of high quality and clean raw materials. Here the economics of production and market conditions play a central role to find out what it does pay to sort out for reclamation and recycling purposes.
- c) To sort out at the source wastes that reduce heating value from the rest of the waste. For instance glass and food waste use energy at incineration plants. Now-a-days these wastes are collected for reclamation purpose.
- d) Power and heat production by incineration, that is incineration should be considered as a form of energy production that replaces other fuels.

The project mentioned in the last section focuses specifically in industrial solid waste management. A new area where municipalities in Denmark have not very much experiences. Handling of industrial waste has usually been a private matter, but due to changes in legislation the authorities will get the necessary powers and authority for imposition of duties on industrial waste producers, for instance industries will be required to introduce a much higher degree of pre-sorting of their waste materials to enable immediate reclamation and recycling. In this connection we should mention that systems for data collection are being designed. Such data can be regularly updated as part of the regular inspection program.

3. Problem formulation.

All these factors mentioned in the last section carry us to the conclusion that the municipalities need a dynamic tool to steer/evaluate the consequences of the different strategies for industrial waste management. Such a tool should support management in both decision-making in connection with the above mentioned strategies providing the relevant information, and in the supervision /control activities of the different industries to register different types of hazardous wastes.

Due to the complexity and the dynamic aspects of the system in study it was decided to develop a computerized tool to tackle the above mentioned problems. Such a tool should provide means to collect and handle the relevant information to support decision-making at different levels.

A very important task in connection with the development of such a tool is the design of a procedure to systematize and classify industrial solid wastes. This procedure should give the possibility to distinguish among different type of wastes in what concerns their damage to the environment, their characteristics for reclamation and recycling, and their characteristics in relation to disposal in refuse dumps. Moreover the computerized tool should provide other facilities as for instance:

- methods to estimate the total production/disposal of solid industrial waste for different types of waste,
- methods to forecast the future development of different areas of solid industrial waste,
- methods to evaluate/simulate the development of the logistic system under different changes.

Moreover, the physical (logistic) system is rather complex (it consists of production, distribution and

disposal of waste) and dynamic, that is under continuous change due economic and technological development at the different industries, see Fig 1.

Another important aspect of the system in study is the fact that the economic and technological conditions for reclamation and recycling are also under continuous changes.

4. Types of management support systems

In general, we can distinguish among 3 types of computer-based management support systems:

Database management systems (DBMS), Decision support systems (DSS), and Management information system (MIS).

The MIS in an organization is a collection of all the application subsystems (forecast, planning, DSS, etc.). The MIS thus represents a viewpoint that integrates all the existing systems in the organization and makes information available to the managers in a readily accessible form. A true MIS should be supported by a versatile DBMS with a nonprocedural query language capability to retrieve data from the integrated database.

The MIS develops in response to the needs of management for accurate, timely, and meaningful data for planning, analyzing and controlling the organization's activities. The MIS accomplishes this objective by providing means for input, processing, and output of data along with a feedback decision-making capability that helps managers to respond to current and future changes in the internal and external environment of the organization.

A well-developed MIS in an organization should be able to respond to the following questions:

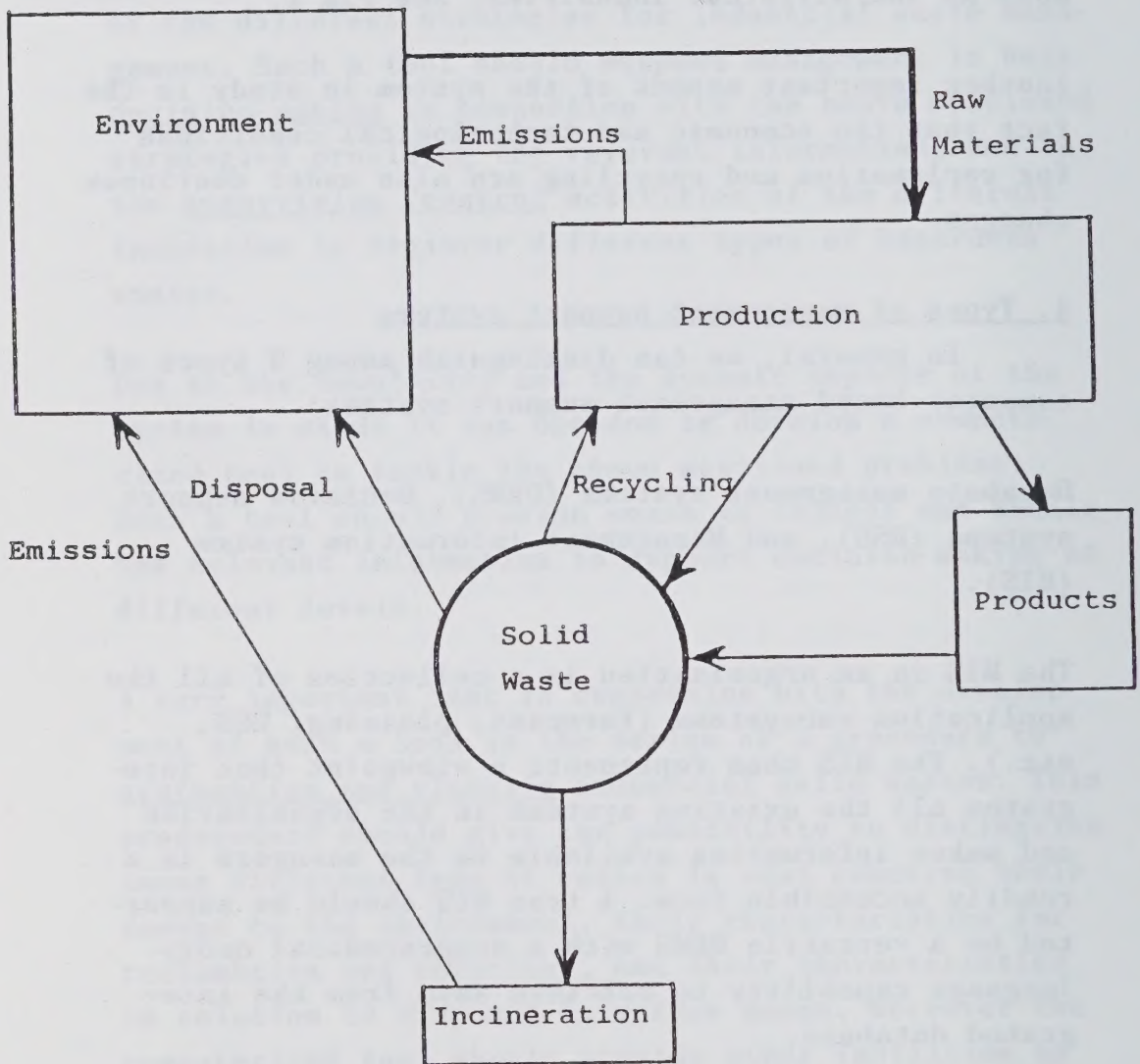


Fig. 1. The Logistic System

what information is needed?
when is the information needed?
who needs it?
where is it needed?
why is it needed?
how much does it cost?

Initially the MIS gets a modest start and addresses a small set of management needs. Gradually more and more demand are made on the system, and these demands are addressed in a patchwork fashion. Eventually the system gets too many patches, and then the need arises to integrate all the components in a well-coordinated fashion. Formal, semiformal, and even informal reporting habits are standardized, definite procedure are set up, and schedules and priorities are established. Information flows are structures for early warning of problems, quick responses to crises, and clear channels for communicating management directives. Finally, the organization gets its MIS.

Within recent years there has been increasing emphasis placed on helping managers make decisions on the basis of good information. As a result, the decision support system (DSS) has become an essential subsystem within the framework of MIS.

A decision support system retrieves information from other parts of the MIS and interfaces with the other subsystems of the MIS. More specifically, the DSS can provide routine detail, summary, and exception reports. If a suitable DBMS is available, then the DSS can provide non-routine information through an ad hoc query facility of the DBMS.

Finally, sophisticated modelling techniques, statistical packages and graphic can be used to analyze available data and provide feedback capabilities to management.

The following characteristics enable the DSS to achieve its objectives:

- it relies heavily in sophisticated techniques of model building, simulation, etc,
- it uses statistical analysis to collect data and to predict trends, and
- it uses features whereby non-computer-oriented people can use it in an interactive mode, for instance using a PC.

5. The information system for industrial solid waste management.

A computer based information system is under development to support the decision and supervision/control functions. The system is developed in response to the need of management for accurate, timely and meaningful data for planning, analyzing and controlling the logistic system. The system accomplishes this objective by providing means for input, processing, and output data along with a feedback decision-making capability that helps managers to respond to current and future changes both in the logistic system, legislation and priorities of the local authorities.

The main goal is that such an information system should evolve to a final decision support system with the following characteristics:

- it helps managers at the upper levels in what concerns decision-making,
- it helps managers at the middle levels in what concerns supervision and control,
- it is flexible and responds quickly to managers' questions,
- it provides "what if" scenarios,
- it takes into account the special information need of the organization where the system is to be implemented,
- it uses features whereby non-computer-oriented people can use it in an interactive mode.

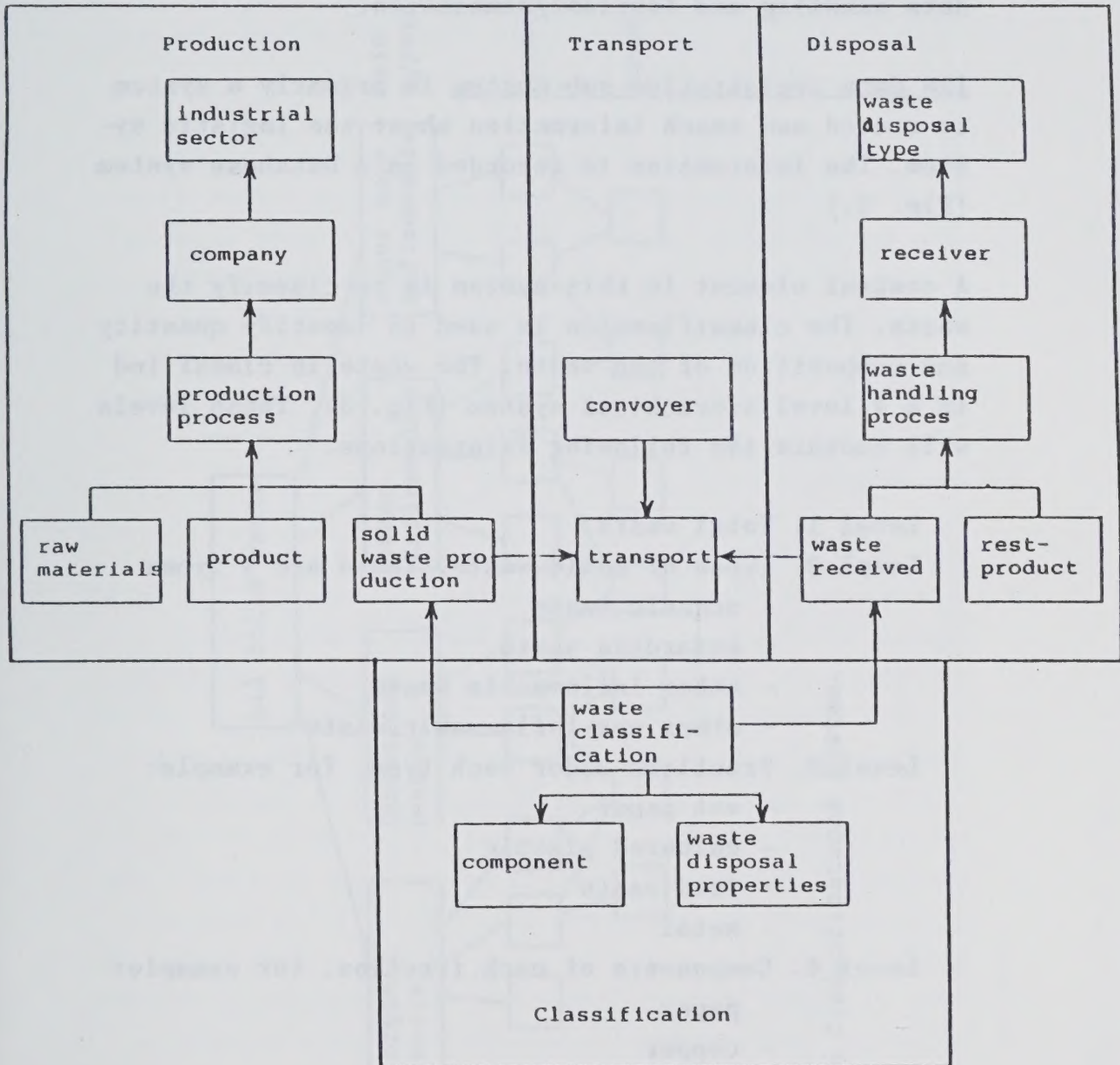


Fig. 2. The Registration System

The information system we are constructing is a first step towards such a decision support system. The information system has 3 subsystems: data registration, data handling and forecast/simulation.

The data registration sub-system is primarily a system to record and search information about the logistic system. The information is recorded in a Database system (Fig. 2.)

A central element in this system is to classify the waste. The classification is used to identify quantity and composition of the waste. The waste is classified in a 4 level hierarchical system (Fig. 3). These levels will contain the following informations.

Level 1. Total waste

Level 2. Types of solid waste. There are 4 types

- organic waste
- hazardous waste
- other inflammable waste
- other non-inflammable waste

Level 3. Fractions under each type, for example:

- wet paper
- coloured plastic
- food waste
- metal

Level 4. Components of each fraction, for example:

- paper
- copper
- PVC
- water

Registration of waste production is primarily based on level 3 information but if level 3 information is unknown, level 2 and even level 1 information can be used. Level 4 information will in general be collected from experts.

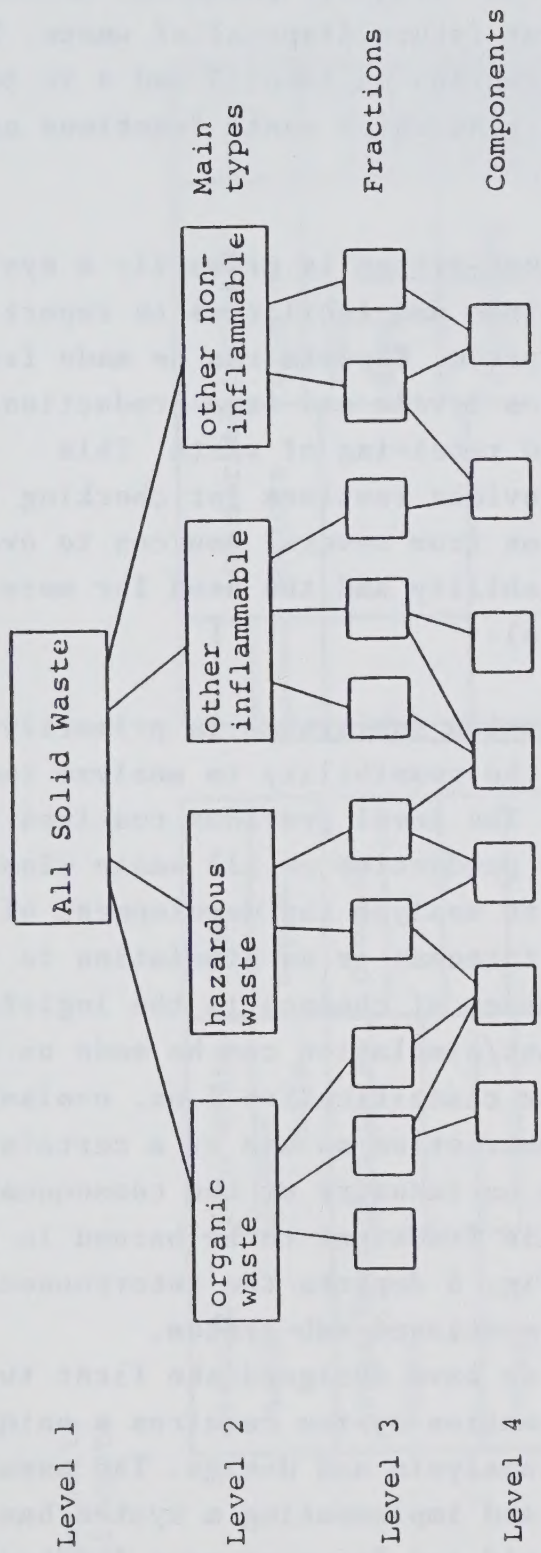


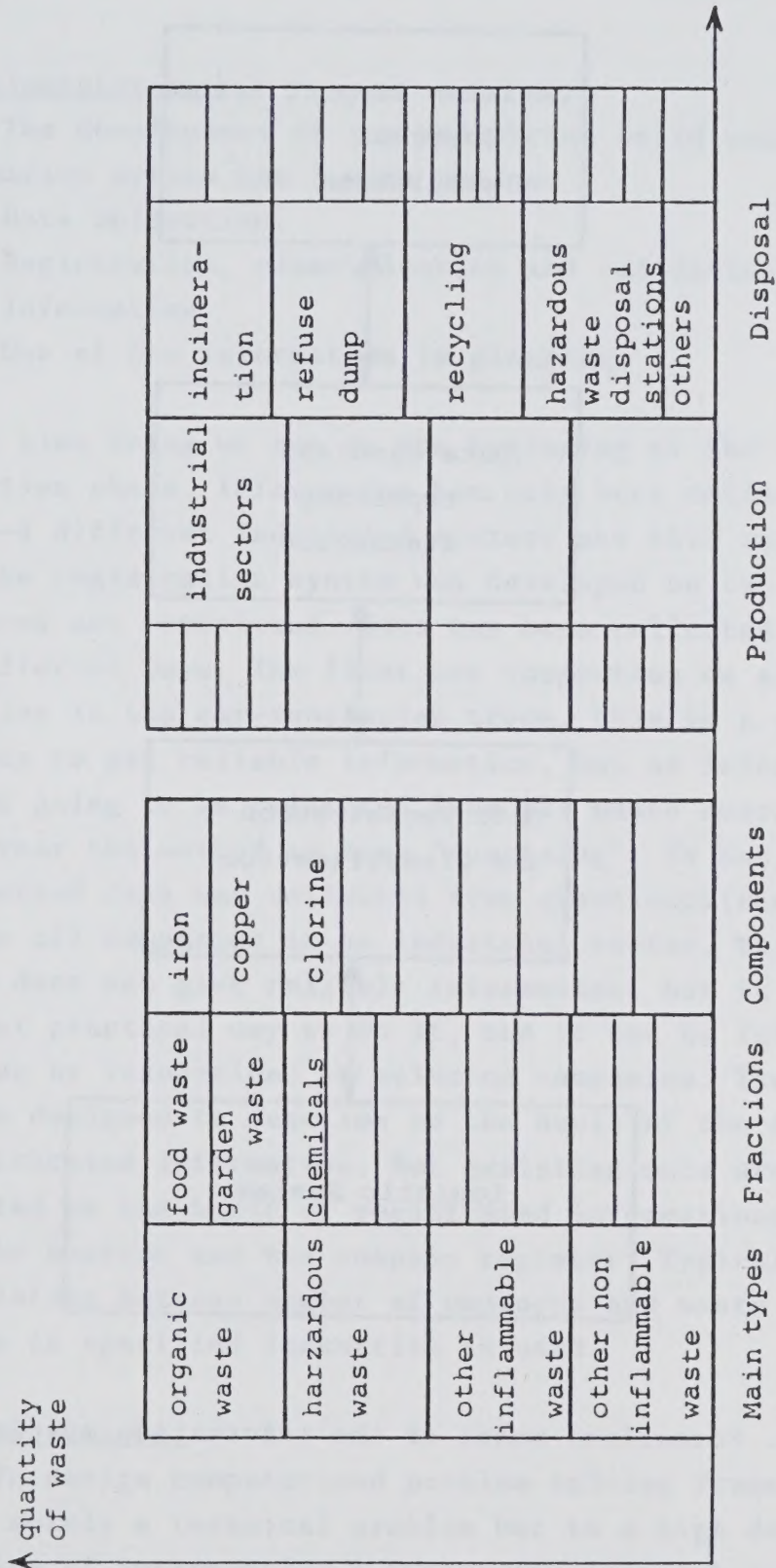
Fig. 3. The Classifications System.

Information from the waste classification level 1 and 2 is to be used in the longterm planning, where decisions are made about future disposal of waste. The more detailed information on level 3 and 4 is to be used to decide and plan which waste fractions are possibly to recycle.

The data handling sub-system is primarily a system that provides routines and facilities to report from the Registration system. Reports can be made from all waste classification levels and from production, transportation, and receiving of waste. This sub-system also provides routines for checking the recieved information from several sources to evaluate their amount, reliability and the need for more information (Fig. 4).

The forecast/simulation sub-system is primarily a system that gives the possibility to analyze the solid waste information. The level provides routines to estimate the waste production on all waste classification levels and to analyze the development of solid waste either as a forecast or as simulation to evaluate the consequences of changes in the logistic system. The forecast/simulation can be made on all levels in the waste classification f.ex. evaluate the consequences of restriction on use of a certain production process in an industry or the consequences of not allowing certain fractions to be burned in refuse disposal plants. Fig. 5 depicts the interconnection between the above mentioned sub-system.

By the time being we have designed the first two sub-systems. The information system requires a unique approach to systems analysis and design. The usual process of designing and implementing a system has to be interfaced with rapid and frequent user feedback to ensure that the final decision support system being built will ultimately address the decision-making needs of the managers.



Solid waste separated in classification levels, production sectors and means of Disposal.

Fig. 4. Report Facilities.

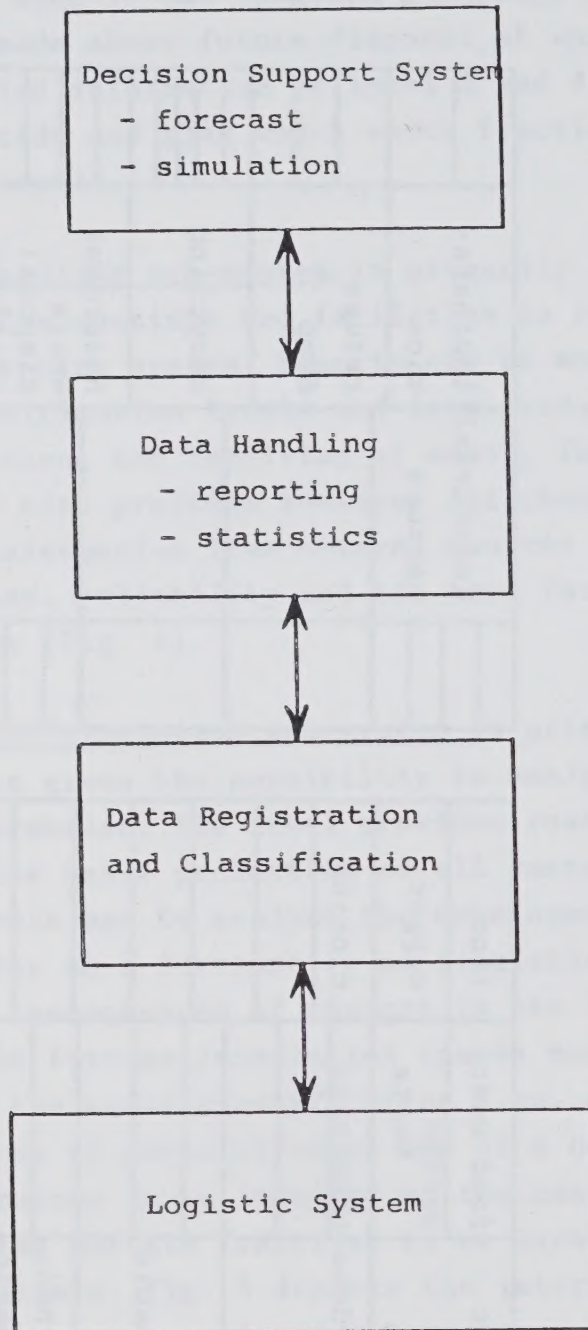


Fig. 5. Formalised model of the information system

6. Implementation.

The development of the industrial solid waste information system has 3 main phases:

1. Data collection.
2. Registration, classification and validation of information
3. Use of the information in planning.

By the time being we are in the beginning of the data collection phase. Information has only been collected from 3-4 different industrial sectors and this was before the registration system was developed so the experiences are restricted. Data has been collected in two different ways. The first was inspection on all companies in the car-reparetion trade, this is a very good way to get reliable information, but as information is going to be collected from all waste sources every year the method is time "consuming". In the second method data was collected from questionnaires send to all companies in an industrial sector, this method does not give reliable information, but it is the most practical way to do it, and it can be followed up by inspections on selected companies. The system is designed to function on the basis of the actual registrated information. Not exsisting data are estimated on the basis of registrated informations from the sources and the company register. Typically the relation between number of employes and waste production in specified industries is used.

7. Final remarks.

To design computerized problem-solving framework is not merely a technical problem but to a high degree a problem of implementing a systematic approach in an organization with little experience in the use of system analysis and computer based-system. The final implementation of such an approach is a long-term learning process based on the interaction of the managers

and the system designers. To develop user-friendly systems to solve first the easiest task is a good way to initiate such a process. Such a problem solving approach should be designed before the process of final data collection because such an approach will tell us which kind of data is relevant for problem-solving. Data should be collected not just to fill up data bases but because such data is useful information for decision-making and supervision/control.

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INFORMATION SYSTEM SUPPORTING ASSESSMENT OF WASTE PROBLEM IN GDANSK VOIVODSHIP

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Abstract

An information system is proposed which can provide a proper information for the environmental impact assessment of alternative technologies. The system utilizes a mathematical model, data base and expert methods. The mathematical model describes production and consumption processes in a form of technological chains and dendrits taking into account sources, recycling and utilisation of wastes. The system is being developed in the case of Gdansk voivodship in Poland.

1. INTRODUCTION

The choice among different possibilities is the essential of decision making process. Luckily, if we may restrict ourselves to consider only alternative decision. More often however we face many possibilities of choice and implications of the present decisions are serious and longterm. Hence, the grate needs for means and tools supporting decision making processes.

Rapid development of the computer technique we have been observing is followed by a great interest in its applications. Microcomputers, from the days they appeared have been stirring up excitement and fascination. Now, they are solidly established as the power tools for helping business, engineers and editors, for example. It is also beginning to look as if regional planers and regional authorities show the needs of computer systems improving their performance and the quality of their work. For the time being these are only simple systems to collect data and to prepare a variety of reports. It seems however that in the nearest future more complex systems will be expected to support analysis and comparing of different strategies of regional development. Especially, that the protection of the environment become a very urgent matter and activities leading to low-waste economy include not only development and application of low waste technologies but

also development and improvement of spatial production links, intra - and inter branches allowing to recycling and reutilization of wastes.

In the paper a computerized information system is presented which can supply suitable information for environmental impact assessment of alternative development strategies. Roughly speaking, the system consists of the data base subsystem and a mathematical model. The model describes the main aspects of the production processes as suppliers of different products and semiproducts from the one side and as sources of wastes from another. According to the adopted ideas, this description takes the form of technological chains and dendrits. The data base subsystem should include mainly technical and economic information on technologies both currently used and potentially implementable.

2. PREREQUISITIES FOR A CONSTRUCTION OF INFORMATION SYSTEM

Active policy in environmental protection is strictly related to rational use of raw materials and decreasing of wastes dumped into the environment. It requires that the problem of wastes should be analysed using a system approach. First of all the wastes should be considered in very general meaning, i.e. solid wastes, and all the kinds of air and water pollution represent the wastes. Secondly the wastes should not be taken into account separately in particular economic processes, but rather recirculation of wastes materials in a regional economy should be considered in complex way, starting from mineral raw materials, passed by manufacturing processes, storage, consumption and wastes recovery as it is presented in the Fig. 1. The approach we would like apply is very closed to the concepts of low-waste economy, developed in UN Economic Commission for Europe. According to the concepts a volume of wastes dumped into environment can be decreased by application of new low waste technologies, but also by creation of spatial - production links, recycling of wastes, a new administrative law and economic regulations. The spatial production links are assumed, as being beyond branches, in form of technological structure (chains and dendrits). In all the activities a number of problems arise to be solved. The solving of the problems can be supported by appropriate information system. In case of Poland such a system is considered as a useful tool for regional authorities. A pilot system is

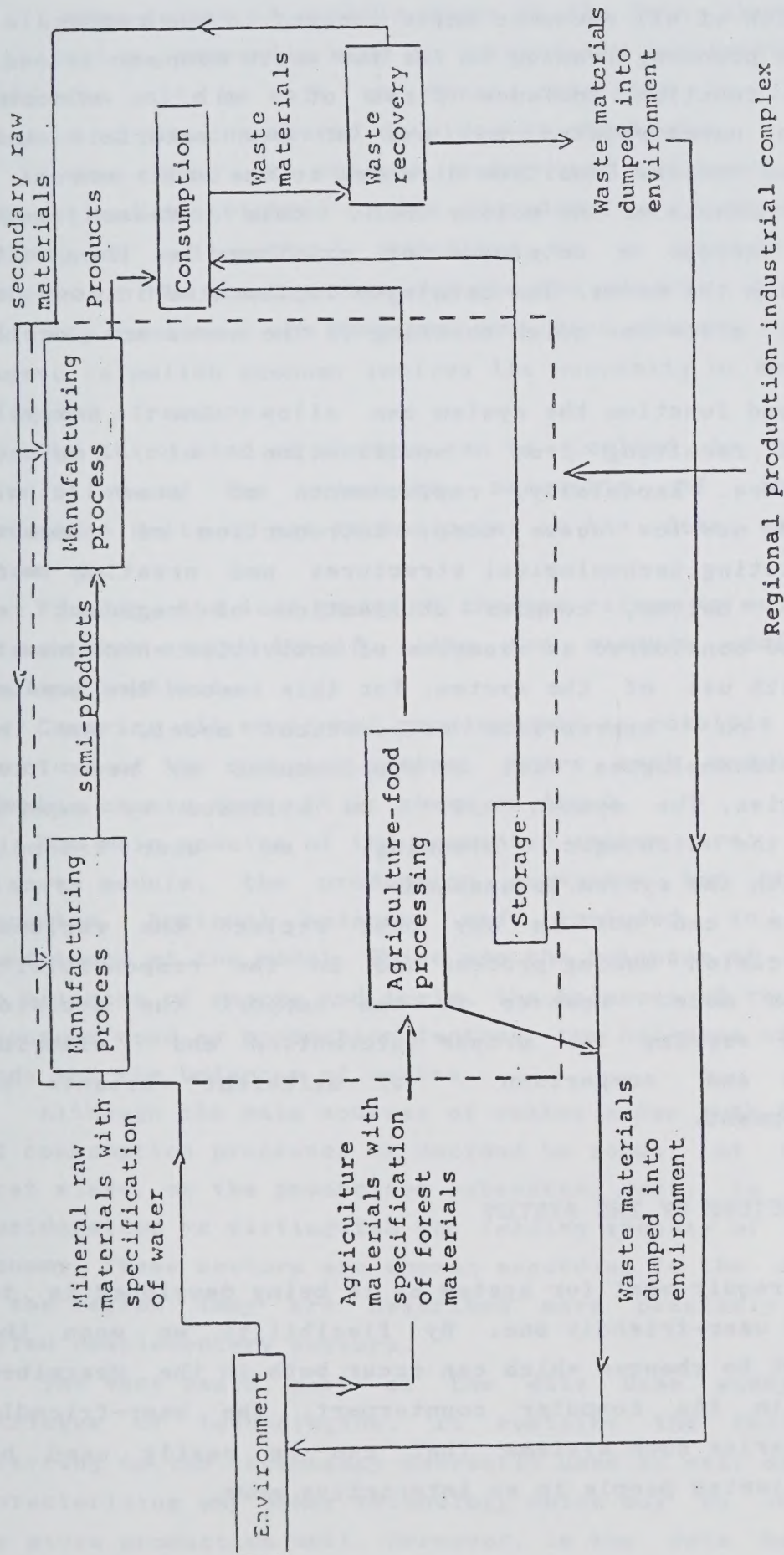


Figure 1. Schematic diagram of waste materials and used commodities recirculation.

constructed for voivodship authority in Gdansk voivodship. The system should aid the authorities in the following main functions:

1. In supervision of all economic units located in the region.
2. In strategic planning leading to the low waste economy.

The first function includes first of all checking of technological norms related to use of raw materials and to production of wastes. Penalties directed to the units are assumed as instruments of the policy. For this reason the system will include a catalogue of existing in the units technologies with the norms. The catalogue implemented in form of data base will allow for quick checking if the norms are really fulfilled.

In the second function the system can allow for analysis of consequences resulting from modification of regional economy structure. Especially, replacements of some old technologies by new low waste ones, introduction of elements connecting existing technological structures and creating more general links, better, complex utilisation of regional raw materials can be considered as examples of activities which should be evaluated with use of the system. For this reason the system will include an appropriate mathematical model, and the catalogue of technologies will be supplemented by new low waste technologies. The system will be utilised by experts dealing with the strategic planning, so user friendly communication with the system is assumed.

The system can not in any case replace the regional authority in decision making process and in the responsibility for the decision made. However it can support the decision making process serving the proper information and allowing for evaluation and comparison of different variants of regional development.

3. GENERAL STRUCTURE OF THE SYSTEM

The basic requirement for system as is being developed is to be flexible and user-friendly one. By flexibility we mean the ability to adapt to changes which can occur both in the described ecosystem and in its computer counterpart. The user-friendly feature characterize such systems that can be easily used by non-computer-oriented people in an interactive mode.

There are many reasons for the mentioned above changes. First of all they relate to modifications of the data, these describing technologies, currently used or potentially implementable in the production units as well as those referring to the different variants of the considered development strategies.

Another kind of changes refer to modification of the mathematical description of the considered ecosystem. As it is well known mathematical modelling is an iterative process. Analysis of the results obtained for the current version of the model may lead to a new improved one. Also changes like these we observe in polish economy implies the necessity of modification of the model structure.

The third kind of changes can be implied by more detailed description of the ecosystem, necessity of including new production units or new technologies in the data base subsystem and so on.

Finally, the last group of changes refers to modifications of the computer system itself, like for example adding new data handling routines.

Covering all mentioned requirements is possible under module structure of the computer system, where each module accomplish suitable chosen task. It is shown on fig.2.

The main modules of the presented system are: the regional balances module, the production subsystem and the data base subsystem. Regional balances are included to ensure the consistency of the model. These are the balances of labor force, the balances of energy and fuels, the balances of the main natural resources used as production factors, the balances of the produced goods and the balances of wastes.

Although the main sources of wastes arise both in production and consumption processes we decided to focus, at least on the first stage, on the production subsystem. Next, to simplify the consideration we distinguish the leading sectors of the regional economy. These sectors are chosen according to the specialization of the region. They are described more precisely than others called complementary sectors.

The very basic part of the data base subsystem is the catalogue of technologies. It contains the full information referring to the technology currently used as well as information characterizing any other technology which may be implemented in the given production unit. Moreover, in the data base subsystem

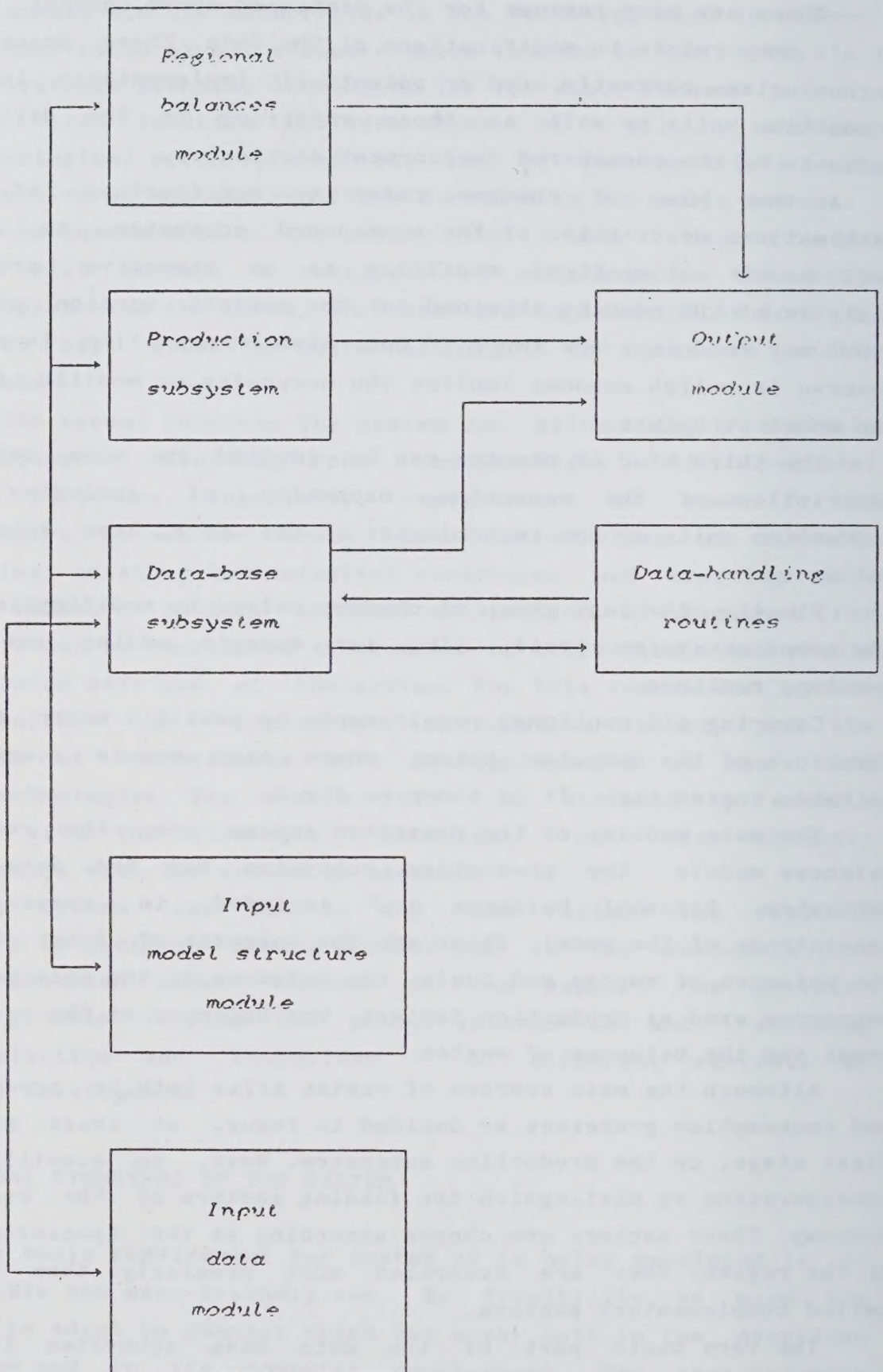


Fig.2. General structure of the information system.

there is stored information which can describe any aspect of the regional economy or may characterize assumed variants of the regional development. In the final version of the proposed system the data base subsystem is to be fed with information either from regional statistical board or prepared by experts.

The data-handling routines are intended to process information contained in the data base subsystem to evaluate trends, for example, some indicators characterizing quality of the regional development and so on.

Input modules are to introduce information (data) into system and to generate the structure of the model as well as to define regional balances. They work in an interactive mode, provide possibilities for checking the received information and, if necessary, allow to repeat this process in a multiply way.

Output module widely using computer graphics, apart from tabular form, is to visualise the obtained numerical results.

4. PRODUCTION SUBSYSTEM

What is important and distinguishing in the approach we present is considering spatial production links. Therefore, we outline now the production subsystem. Its base element is production unit. Without going too deeply into details, it may be a plant, a part of plant or a group of plants according to the needs, particular sectors, sources of wastes and theirs possible recycling.

The input streams entering a production unit, see fig.3, consist of: N1 - the main natural raw materials, N2 - auxiliary natural raw materials, P1 - the main semi-finished products, P2 - auxiliary semi-finished products, E - energy, L - labor force.

The output streams are composed of the main product, the by-pass products, the waste materials and losses. A part of the wastes may be recycled inside the production unit.

To simplify the description only one main product is assumed for each production unit. Thus, all inputs and remaining outputs can be expressed according to the level of this main product.

Next, we assumed that all outputs of the production unit depend linearly on the entering input flows. The technological coefficients and the maximal level of production are defined on the base of information contained in the catalogue of

The production subsystem of the regional economic system can be viewed as a topological structure composed of nodes and branches. The nodes represent production units. The branches represent interconnections between nodes resulting from the cooperation.

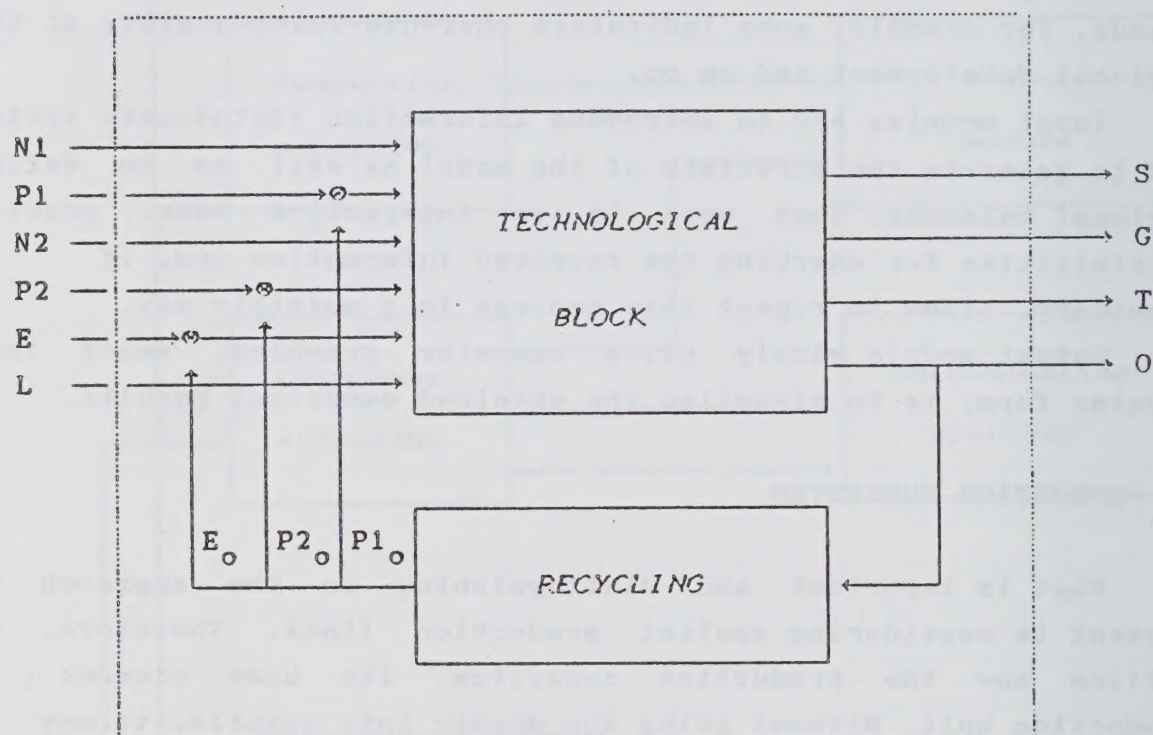


Fig.3 Production unit.

The very basic structures are the technological chains. They are defined as sequences of production units such that either the whole or only a part of the output of one production unit enters as an input to another. An example of the simple technological chain with recycling is given on the fig.4.

There are possible more rich and complicated technological structures. For example, the technological dendrites are sets of interconnected technological chains which are formed either on the base of the same natural raw materials or on the base of the same final products.

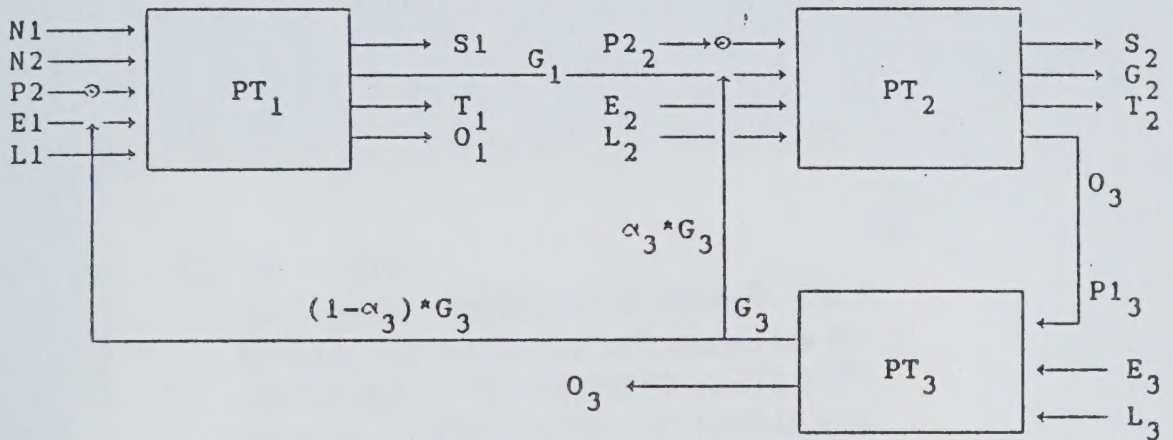


Fig.4 Simple technological chain with recycling

The mathematical description of the technological chains, dendrites and more complex structures result from applying of the energy and mass conservation laws.

By applying different technologies in each production unit, according to the information contained in the catalogue of technologies, we obtain different technological structures of the considered regional production subsystem.

5. FINAL REMARKS

In the paper a computerized information system is proposed supporting activities of regional authorities in assessment of waste problem. The pilot system is being developed in the case of Gdansk voivodship, which economy is strongly linked with Baltic sea, and with its resources. In the current state of the work, data required in the system are collected for the leading in the region sectors. The proposed system is intended as a tool aiding the authority in supervising the waste management and analysis of the alternative development strategies.

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